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DIPLOMARBEIT

Simulation-supported comparison between energy demand and energy supplied by active solar systems in an existing building in Vienna: A Case Study

ausgeführt zum Zwecke der Erlangung des akademischen Grades

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Abstract

This master’s thesis analyses the energy performance of a building in the context of urban building stock equipped with solar systems in order to achieve self-sufficiency.

Around 70 per cent of the residential building stock built in the years 1945 to 1991 is poor built or inadequate renovated reporting a heat demand much higher than today's conventional standards. More than 2.5 million are considered potential for renovation. Consequently, buildings account for a substantial proportion of primary total energy consumption and thus are largely responsible for the greenhouse gas emissions. In the new building construction already ambitious targets and planning requirements are realized by minimizing the energy consumption or the use of renewable energies. But the annual construction rate of new residential buildings in Austria is ca. 1-2 per cent of the overall living space. While in Austria the thermal rehabilitation is promoted extensively, Austria lags behind the goal of an annual renovation rate of 3 per cent of the housing stock.

The study explored the potential of active solar systems in Vienna on an existing building with a dynamic simulation software featuring both, a photovoltaic system and solar thermal system for hot water and heating demand. The results were subsequently compared and evaluated according to such different criteria as domestic hot water, heating and electricity demand. Furthermore a cost calculation was carried out.

On the basis of the results of this research, it can be concluded that the solar activation of existing urban buildings which require refurbishment can contribute to the most of the hot water demand and modest energy exports of photovoltaic power. Further research and detailed planning of the building services could offer more convenient results

Zusammenfassung

Diese Masterarbeit analysiert die Energieeffizienz eines Gebäudes im Rahmen der städtischen Bausubstanz mit Solaranlagen ausgestattet, um die Selbstversorgung zu erreichen.

Rund 70 Prozent des Wohngebäudebestands aus den Jahren 1945 bis 1991 wurde schlecht gebaut oder unzureichend saniert. Laut Berichterstattung ist der Wärmebedarf wesentlich höher als die üblichen Standards vorschreiben. Mehr als 2,5 Millionen sind renovierungsbedürftig. Darüberhinaus machen Gebäude einen erheblichen Anteil der Gesamtprimärenergieverbrauchs aus und sind damit weitgehend für die Treibhausgasemissionen verantwortlich. Im Neubau werden bereits ehrgeizige Ziele und Planungsanforderungen gesetzt den Energieverbrauch zu minimieren und die Nutzung erneuerbarer Energien einzusetzen. Aber die jährliche Baurate von neuen Wohngebäuden in Österreich liegt bei ca. 1-2 Prozent des gesamten Wohnbestands. Während in Österreich die thermische Sanierung weitgehend gefördert wird, hinkt es doch hinter dem Ziel einer jährlichen Sanierungsrate von 3 Prozent des Wohnungsbestandes zu erreichen.

Diese Arbeit erforscht das Potenzial der beiden eingesetzten Solarsysteme, einer Photovoltaikanlage und Solaranlage für Warmwasser- und Heizungbedarf, auf einem bestehendem Wohngebäude mittels eines dynamischen Simulationsprogrammes. Die Ergebnisse wurden nach Kriterien wie Warmwasser-, Heizung- und Strombedarf verglichen und bewertet. Folglich wurde eine Kostenanalyse durchgeführt.

Auf der Grundlage der Ergebnisse dieser Untersuchung kann festgestelltwerden, dass die Aktivierung der Solaranlagen bei bestehenden städtischen Wohngebäuden, eine umfassende Sanierung erfordern. Es sind lediglich ein Großteil des Warmwasserbedarfs und geringe Energieexporte der Photovoltaikanlage möglich. Weitere Forschung und detaillierte Planung der Haustechnik könnte aufschlussreichere Ergebnisse bieten

List of Acronyms and Abbreviations

AC	Direct Current
ACH	Air Exchange Rate
AM	Air Mass
BUS	Binary Unit System
CG	Cost Group
DC	Alternating Current
DHW	Domestic Hot Water
EDSL	Environmental Design Solutions Limited
EEA	European Environment Agency
G	Global solar radiation
G_{dir}	Direct solar radiation
G_{dif}	Diffuse solar radiation
GHG	Greenhouse gases
HWD	Hot water demand
IMF	International Monetary Fund
KPC	Kommunalkredit Public Consulting
kW	kilowatt
kWh	kilowatt hour
l/d/p	Litre/Day/Person
MW	Megawatt
NNE	North North East
OIB	Austrian Institute of Construction Engineering
ppm	parts per million

PV	Photovoltaic
SDH	Solar District Heating
STC	Standard Test Conditions
SWW	South West West
TAS	Thermal Analysis Software
TSD	TAS Simulation Data
TED	Total Energy Demand
UNFCCC	United Nations Framework Convention on Climate Change
W	Watt
WCC	World Climate Conference

1 INTRODUCTION

Climate change is one of our greatest environmental, social and economic threats nowadays. Energy plays a fundamental role in supporting all aspects of modern life. And this sector is responsible for the majority of anthropogenic greenhouse gas (GHG) emissions (EEA, 2012). Global GHG emissions have grown since pre-industrial times with an increase of 70 per cent between 1970 and 2004 (IPCC 2014). Half of EU greenhouse gas emissions from fossil fuels come from households and industry. In order to minimize the GHG emissions the European Union has set ambitious targets. On the latest Conference in Doha 2012 the EU has set new goals for the period from 2013 to 2020 committing itself to reduce the GHG emissions by at least 20 per cent compared to 1990 levels. For 2050 EU is planning to reduce the GHG emissions progressively by 80-95 per cent against 1990 (UNFCCC 2014). This implies the exit from the fossil energy supply and implementation of renewable energy technologies.

The largest energy consumers in Austria are the poor insulated houses and housing estates from the 50s to the early 80s. Around 25 per cent of the total energy consumption are used by households. Ca. 72 per cent of household's end energy consumption accounts for space heating (Figure 1). Households are therefore responsible for a large proportion of CO_2 emissions in the country.

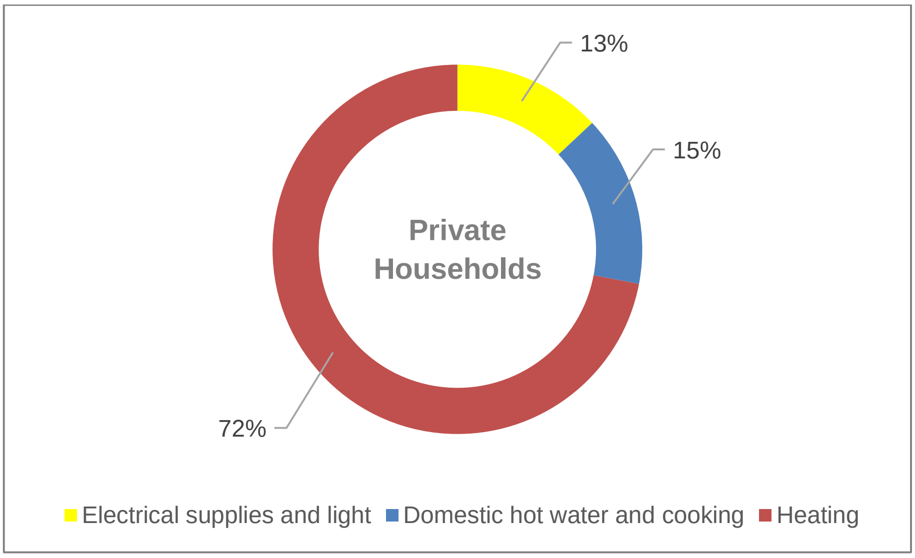

Figure 1 End energy portion by categories in private households (BMWFW 2014)

1.1 Objective

Solar thermal heating systems as well as photovoltaic systems offer great potential for long-term reduction of pollutant emissions and energy costs. Especially in the area of the building stock, in combination with an energy-saving renovation, high savings can be achieved. The goal of this study was to examine the potentials of solar systems on existing buildings in Vienna. This includes an analysis of a building’s ability to apply photovoltaic and solar thermal systems in order to reach self-sufficiency. For this approach a dynamic simulation software, EDSL Tas, was chosen to perform required simulations. Calculations of the building’s heating demand, domestic hot water demand and electricity consumption were carried out. Three different states of thermal refurbishment were performed. Further study subject was to evaluate the expenses in respect of investment and operation costs. That raises two important questions. Is a fundamental contribution of solar systems attainable? And are this systems profitable?

1.2 Motivation

One critical indicator of environmental impact is our energy exhaustion. Building structures are a substantial cause of primary total energy consumption. With each passing day, the Earth’s available fossil resources are decreasing. We have reached the point at which we can no longer ignore the consequences of global warming. The global mean temperature has increased by about 0.8°C since the industrial revolution. The past decade (2001-2011) was recorded as the hottest since measurement began (EEA 2012). Scientific predictions state that temperature increase until 2100 will be in the range from 1.5°C to 5.8°C.

Around 40 per cent of greenhouse gases result from building construction and building utilisation and this has a decisive effect on global warming. Research by the International Monetary Fund (IMF) has shown that there is a direct link between economic fluctuations and access to energy. “In 2008, the top carbon dioxide (CO_2) emitters were China, the United States, the European Union, India, the Russian Federation, Japan, and Canada. These data include CO_2 emissions from fossil fuel combustion, as well as cement manufacturing and gas flaring. Together, these sources represent a large proportion of total global CO_2 emissions” (EPA 2014). Furthermore, ca. 10 per cent of energy use goes on the manufacture of materials, building processes, transportation and building materials. The construction sector uses ca. 50 per cent of all the worlds' materials. Building construction and civil engineering are responsible for ca. 60 per cent of generated waste (Hegger et al. 2008). Considering the relatively long live span of buildings, all decisions and actions regarding the building process have long term effects. The population is constantly and rapidly growing each day. This means that more buildings will be built and, consequently, more resources will be used and more emissions released. Therefore, it is substantial that architects implement renewable energy technologies in their designs. Not only in new constructions, but also for the existing building structure.

Table 1 The estimated exhaustion of fossil sources over the next 200 years (Source: Hegger et al. 2008)

Fossil source	**Year**
Mineral oil	41
Gas	62
Coal	200
Uranium	40

Fossil energies make up 86 per cent of global consumption (Hegger et al. 2008). Table 1 shows the predicted date of the exhaustion of each fossil source in the next 200 years. All reserves of petroleum and natural gas will be depleted by the end of the 21st century with only coal reserves available for a longer period of time. Additional fossil reserves, yet to be discovered, can only be estimated. Even if new major fossil fuel reserves are to be discovered, it would not change the fact that the supply of fossil fuels is limited. If the uncontrollable effects of increasing temperatures still persists, radical change in consumer and economic behaviour is essential in the coming years. However, reorientation is not a matter of technology and business but of politics and society.

Solar energy is our oldest and our newest form of energy. It can be generated at its place of use: i.e. on your roof.

Table 2 shows the comparison of advantages and disadvantages of fossil and renewable energy resources.

Table 2 Comparison of fossil and renewable energy sources (Source: Hegger et al. 2008)

Atomic and fossil energy	Renewable energy
Require massive environmental interventions with tectonic effects on the Earth (emissions to water, air and atmosphere)	Emission free
	Inexhaustible → guaranteed substantial energy supply
Are exhaustible → increased prices	Available everywhere → less infrastructure needs
Not everywhere available → high infrastructural expense, existential dependency and political conflicts	Political independency
Becoming more expensive due to the underlying circumstances	Becoming less expensive due to improvements in technology

In addition to the enormous potential of solar energy one another factor plays a major role in applying solar systems. In 2009 in the urban space of Vienna, 168,167 buildings were counted according to latest available data from the houses and housing census. Almost half of these are single family homes, i.e. homes with one or two apartments (82,273), which represents an increase of +11 per cent compared to the year 1991 (74,017). 34 per cent accounts for multi-family houses (57,284), which shows a +12 per cent to 1991 and 17 per cent are not used for residential purposes (28,610) and have no major changes compared to 1991 (Statistik Austria 2011).

As mentioned earlier single and multifamily dwellings account for the majority of the urban building stock. And the number is gradually increasing. This brings to the question how this existing building stock can contribute to the sustainable urban future. The existing poorly built structure in Vienna does not only waste enormous amounts of fossil energy but also contributes to the CO_2 emissions.

The City of Vienna extended until December 31, 2015, the action for the subsidies of solar thermal systems in the annual rate of one million Euros. Funding is for stationary solar thermal systems and solar thermal heat pump combined systems for hot water and heating. Vienna wants to support those who count on renewable energy. The subsidies guidelines have been fundamentally revised to meet the needs of subsidies participants. For instance, the funding base has been changed. Previously the installed collector area was crucial, whereby now the solar gain of the solar system is used. Solar energy has been evolving steadily over the last several decades. We are now in a situation where the demand for solar energy is bigger than the supply. This puts the solar energy industry in a very interesting position.

1.3 Thesis Structure

This master thesis is structured in seven sections. First section provides introduction into the topic and the main objective. Second section gives general information regarding the historical development of the solar systems, their properties as well as the market development of solar systems in Austria. Section 3 describes the methodology and approach to the case study. Section four shows the results conducted including discussion of those results. Section five includes the final conclusion and future research. Further sections contain references and appendixes.

2 BACKGROUND

2.1 Overview

This chapter describes the background of the study, what solar energy is about, and the history of solar energy systems. Furthermore, it describes energy resources, the general principles involved and the Austrian solar systems development until 2013.

The publication in the *Baumagazin* from 2010 by Professor A. Mahdavi from the TU Vienna Institute of Technology includes a critical review of the potential with respect to energy-plus houses in the urban context of existing buildings. The study intended to show in how far the urban building stock has a potential in terms of Energy-plus house. An existing multi-storey residential building in Vienna was studied. A readily available spacious area on the roof was applied by solar collectors. The assumptions were generously assumed that the assessment has been exempted from very favourable conditions. The energy requirements for domestic hot water, heating and electricity were estimated. Several variants were taken into account in the thermal building envelope and as weather input the average solar global radiation intensity was used. This was the incentive to examine the potential of urban existing multifamily dwellings with respect to energy-plus houses.

2.2 Theory of Solar Energy

2.2.1 Energy resources and renewable energy sources

Fossil fuels are concentrated sources of energy that were created from animal or plant remains over very long periods of time. Fossil fuels include oil, natural gas, coal, lignite and peat. However, they are also the result of the conversion of solar radiation over millions of years, which also makes them a form of stored solar energy. In chemical terms, fossil energy resources are based on organic carbon compounds. The combustion of these with oxygen releases not only energy in the form of heat but also the greenhouse gas carbon dioxide (Quaschning 2008). If an organic substance is not used immediately it is transformed, over a long time period, into fossil-biogenic energy sources and these - the fossil-mineral substances - form the Earth’s energy resources. But our consumption is exceeding the supply of fossil resources as a result of which the energetic state is out of balance, which means that we are taking more from the Earth's resources than it can recover (Hegger et al. 2008). Just to clarify the timeline that we are talking about: Mineral oil and natural gas need 20 - 440 million years to develop and coal needs 10 - 370 million years. This means that the Earth's fossil resources do not have enough time to recover given the speed at which we are exhausting them.

The total energy available on the Earth comes from three main sources: geothermal energy, gravitation and solar radiation. The largest of these (99.9 %) is solar radiation (Hegger et al. 2008). The sun is a tremendous energy source and greater than all the energy sources on earth. In just three hours it emits the same amount of energy to the earth, as is consumed by the Earth's entire population in a year. Much more solar potential is available than we could ever use and this is almost free and inexhaustible. But most of the energy emitted by the sun does not reach the earth's surface. Besides that, additional problem is how to collect it on a large scale. "We would need a big area of the earth's surface to capture enough to convert it into electricity for all our needs. In fact, someone has calculated that it would require around 1 million km² of land surface" (Thorpe 2011).

2.2.2 History of solar systems

For thousands of years humans have been using solar energy to make fire and even for passive heating. In the early 19th century some significant discoveries were made in the field of solar power. In 1839 the French scientist Edmond Becquerel discovered the photovoltaic effect which explains how electricity can be generated from sunlight. A few decades later Augustin Mouchot, a mathematician and physicist who believed at that time that fossil sources would someday run out, was looking for new alternative energy sources. He invented the first solar power engine which converted solar energy into steam power. These engines were the predecessors of modern parabolic dish collectors. Since then, scientists have made great progress in the development of solar power technology. Today we have two main kinds of panels: those which heat fluid or air and those which generate electricity. But while solar thermal technology has developed enormously, photovoltaic power continues to be very inefficient and solar cells are mainly used for the purpose of measuring light. Today solar technologies are spread globally and an effort is being made to implement them as much as possible. Constant development means that renewable technology systems are available locally.

2.2.3 Solar geometry, angles and orientation

This chapter looks at the solar radiation that reaches the earth, the orientation and angles of solar panels and why these matter in the planning of solar systems. The solar energy supply to the Earth depends upon astronomical circumstances, such as season, daytime, latitude, and meteorological influences. The Earth's angular orbit around the sun and its axis means that the supply of solar radiation to the Earth varies. The solar altitude (angle of the sun's height) and the azimuth (direction facing away from the north) play an essential role in the design of solar systems (Figure 2). The further south a site is located within the northern hemisphere, the higher the position of the sun in the sky at midday when solar radiation reaches its peak. Figure 3 shows the path taken by the sun across the sky on the shortest day in December and longest day in June. The sun shifts throughout a year which leads to more exposure in summer and less in winter. Due to the inclination of the Earth's axis, days in summer are longer than in winter and, therefore, the sun reaches higher positions in summer than in winter.

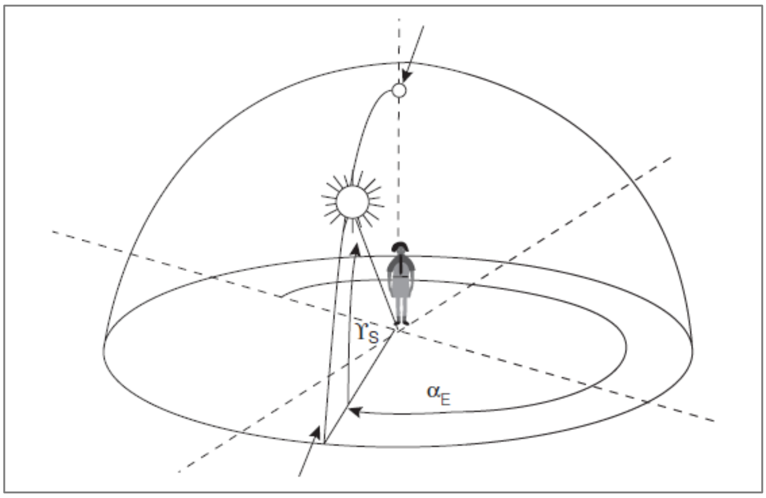

Figure 2 The sun's relative position in the sky to an observer can be defined from two values: γS = solar elevation; αE = azimuth

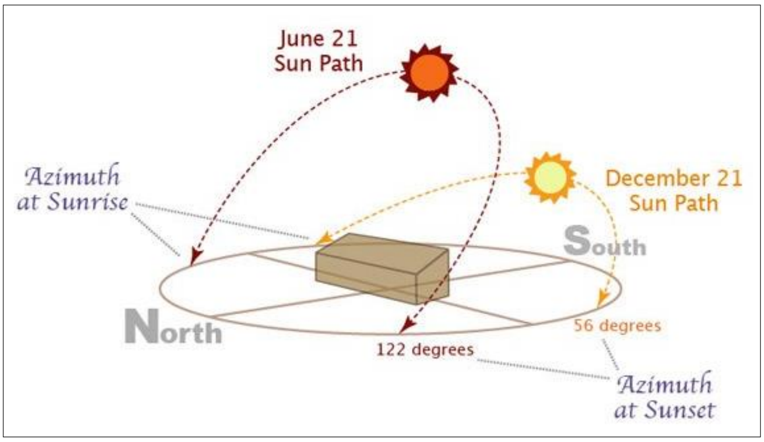

Figure 3 The sun's path during summer and winter (Source: Mel@By Example 2013)

Meteorological events have a significant effect on solar radiation. From a vertical position, sunlight takes the shortest path through the atmosphere. When the sun is at a lower angle, the path through the atmosphere is longer and this increases the absorption and scatter of solar radiation as a result of reducing the intensity. This proportion between the length of solar radiation and the thickness of the atmosphere is called Air Mass (AM). When the sun's position is vertical, AM equals 1. The lower the position of the sun, the higher the AM and, therefore, the lower the radiation. Figure 4 shows that the amount of irradiance reaching the Earth's surface is affected by the amount of atmosphere through which it passes.

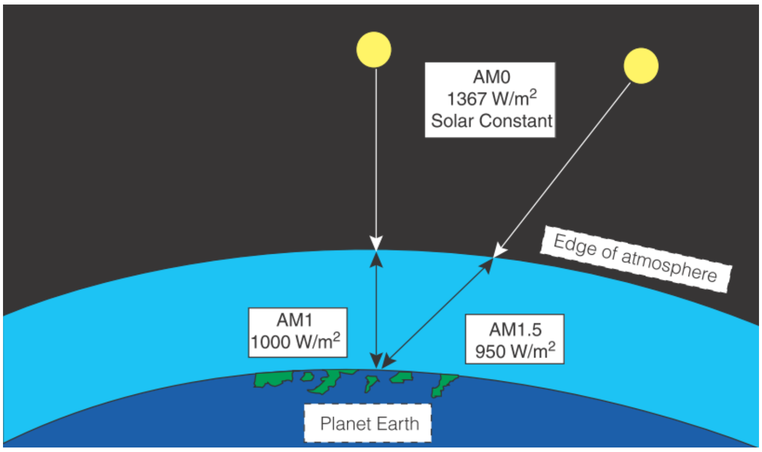

Figure 4 The amount of irradiance reaching the Earth's surface (Source: Laughton 2010)

Essentially, solar irradiation reaches the Earth's surface with a power of 1,367 $W.m^{-2}$. This value is known as the solar constant. The amount of radiation reaching the surface depends on the angle of solar elevation which varies throughout the day. In a year the sun radiates about 1.5 sextillion kWh of energy (Quaschning 2008). As solar radiation passes through the atmosphere about 30 per cent is reflected. Half of the available radiation finally reaches the Earth's surface due to the interactions of atmospheric elements. This radiation is called diffuse radiation (G_{dif}). The radiation that strikes without changing direction as a result of atmospheric elements is called direct radiation (G_{dir}). Global radiation (G) is the sum of direct and diffuse radiation (Figure 5).

The intensity of radiation and rate of direct and diffuse solar radiation vary strongly depending on cloud cover. An inclined surface receives three types of solar irradiation: direct, diffuse and reflected irradiance. Each is affected by the angle of the tilted surface as well as by the sun's height (solar altitude or elevation). Maximum irradiance occurs when the light from the sun is perpendicular to a surface (Figure 6). Because the sun changes its position during a day and season, there is no ideal fixed position. Automatic tracking systems can be used to ensure that surface position and angle are always optimal, but these are not used for solar domestic water heating systems. However, a solar panel performs best throughout the whole year placed at an angle of 45°.

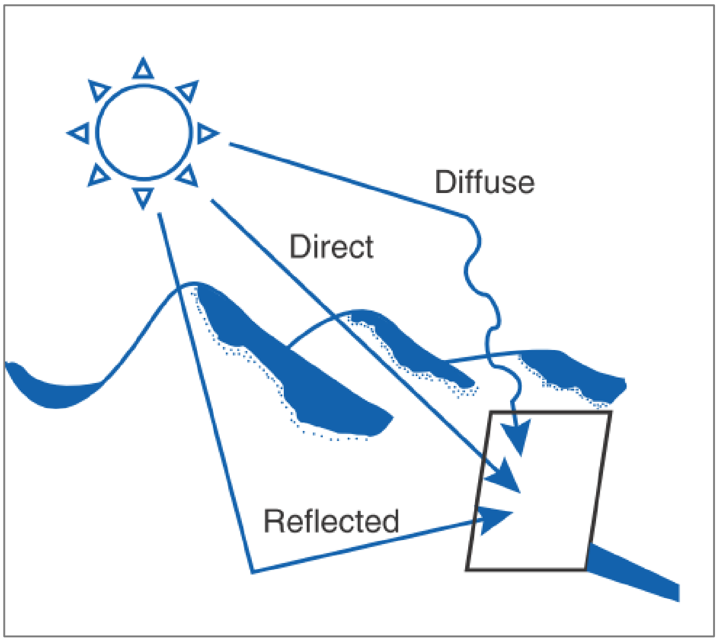

Figure 5 Direct and diffuse solar irradiation (Source: Laughton 2010)

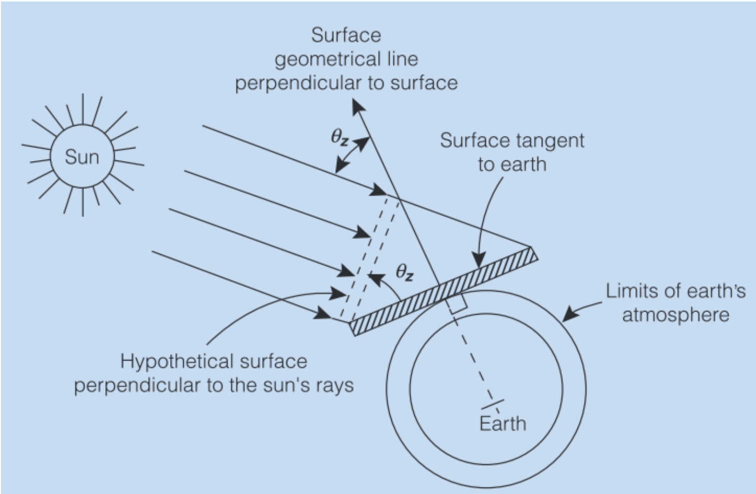

Figure 6 The intensity of irradiation is reduced when a surface faces away from the perpendicular to the sun (Source: Laughton 2010)

2.2.4 Global solar radiation in Austria

Depending upon the time of day, cloud cover and haze etc., the level of global radiation striking the Earth's surface varies between 50 and 1,000 W.m^{-2}. In Austria global radiation can reach approximately 1,100 kWh.m^{-2} in parts of Upper and Lower Austria and over 1,400 kWh.m^{-2} in the Southern Alps (Figure 7). These numbers refer to a horizontal plane unless otherwise specified. However, as the radiation incidence angle changes over the year, solar radiation values deviate from those specified in figure bellow.

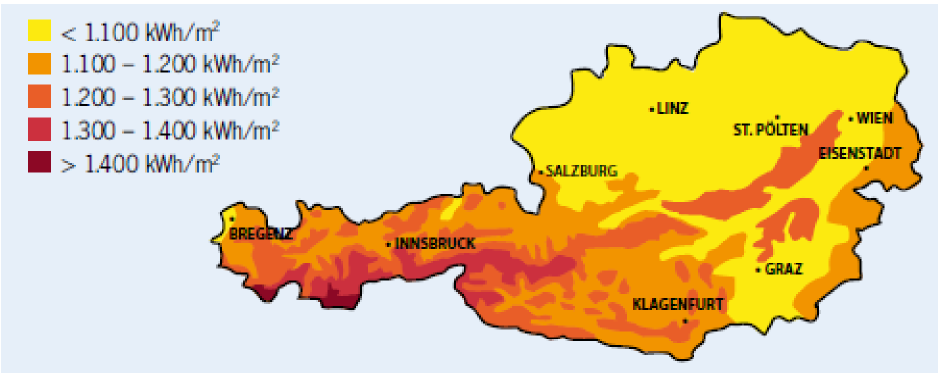

Figure 7 Average total annual solar radiation on a horizontal surface in Austria (Source: ZAMG 2013)

2.3 Market development of PV and Solar Thermal Systems in Austria

The market development of solar thermal plants and photovoltaic in Austria has been documented since 1975 (solar thermal plants) and the early 1990s (PV). Data has been obtained by asking installers and manufacturing companies and collecting information about state funding by the OeMAG as well as by climate and energy funds and the KPC (Biermayr et al. 2013). In the early 1970s, the oil crisis led to a rapid search for new technical alternatives as a result of which solar plants became a subject of research and development. This led to the implementation of solar systems for hot water and heating support, although these were quite expensive, technically unreliable and inefficient due to a lack of practical experience. In the late 19th century a solar thermal plant had been discovered, practically tested and developed for more than 40 years in the United States even though this development of solar technology was unknown in Europe (AEE 2012).

2.3.1 Market development of PV systems

In the 1990s, similar numbers of grid-connected and stand-alone PV systems were installed. Eventually however, subsidies led to the growth of the market for grid-connected systems. Due to the Green Electricity Act with a 15 MW_{peak} cap led 2004 to a collapse in the Austrian domestic market which reached its lowest point in 2006. New investments by individual states led to an increase in 2007 and 2008. The capacity of newly installed PV facilities in 2009 was 20.2 MW_{peak} and 2010 a new maximum of about 42.9 MW_{peak} was reached. But numbers of 2012 reached new highest values of new installed PV systems with around 175.5 $MW_{peak.}$ This enormous growth rate was caused by the price reduction of PV systems as well as advanced initiatives of the country in the last years. Compared with 2011, newly installed grid-connected PV power almost doubled in 2012 to 91.7 per cent. In contrast, stand-alone systems showed a decrease of 68.2 per cent. In terms of total installed capacity in 2012, the average annual rate of change of the last 10 years is 45.2 per cent, whereby the most growth rate happened in the last four years (Figure 8). The cumulative capacity of all, grid-connected and stand alone PV systems increased in 2012 to 362.9 MW_{peak}. The operating PV systems in Austria lead 2012 to an electricity production of 337.5 GWh (Biermayr et al. 2013).

The overall installed PV power in Austria in 2012 sums up to ca. 175.5 MW_{peak} grid-connected systems and 220 kW_{peak} stand alone systems. This comes up to 13,200 installed PV systems in Austria.

The most commonly installed cell types are monocrystalline and polycrystalline solar cells. In 2012 polycrystalline cells were in the majority with 75 per cent fraction. While in 2010 the monocrystalline cells represented 53 per cent of total installed capacity, in 2012 this fraction decreased to 23 per cent. As an underpart role the thin film cells showed a distinctive decrease compared to 2011 from 9 per cent to about 1 per cent in 2012.

Rooftop PV systems are still the most common - around 93.4 per cent. The second most common are free standing facilities (4.4 %), followed by built-in roof systems (1.6 %). Systems built-in to façades (0.6 %) are the least common in Austria.

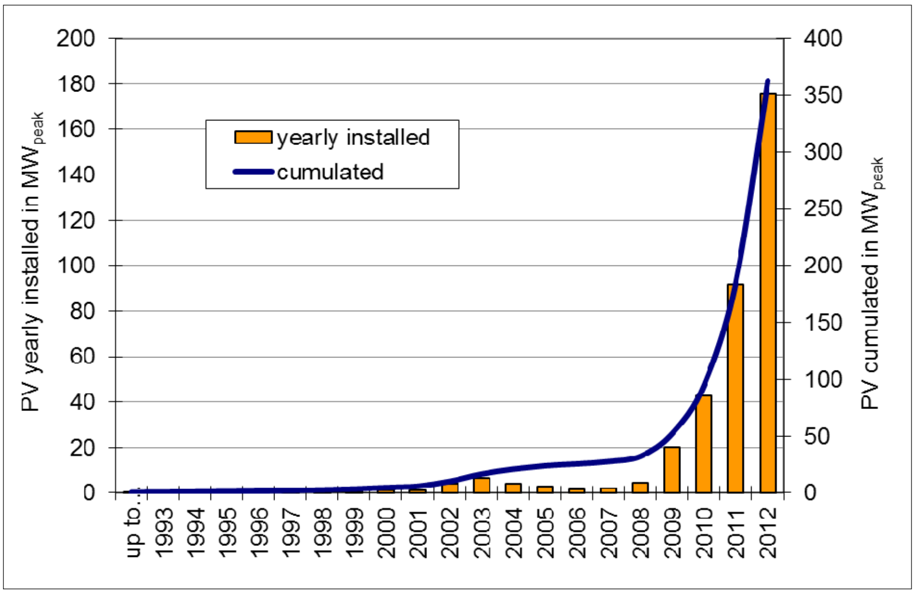

Figure 8 Annual levels of newly installed PV power in kW_{peak} in Austria between 1992 and 2012 (Source: Biermayr et al. 2013)

2.3.2 Market development of solar thermal systems

In order to compare the quantity of installed thermal solar collectors with previously discussed PV installed power, the data is shown in terms of installed power in $kW_{thermal}$ (kW_{th}). In 2012 an amount of 209,630 m² of thermal collectors were installed in Austria. This represents a capacity of 146.8 MW_{th}. Most of the installed systems were glazed flat-plate collectors (200.800 m² which is equivalent to 140.6 MW_{th}), followed by vacuum collectors (5,590 m² and 3.9 MW_{th} power), unglazed flat-plate collectors (2,410 m² and 1.7 MW_{th}) and air collectors (830 m² and 0,6 MW_{th}).

In the period of 2000 and 2010 the average annual increase in the market was 7 per cent. This means that over the ten-year period the annual installed capacity almost doubled from 117 MW_{th} to 200 MW_{th} (Figure 9). The first upturn came in the 1980s when solar thermal collectors were used for water heating and swimming pools. Initiated by various research projects, the scope of solar thermal systems expanded to room heating systems in the 1990s. Decreasing oil prices around the millennium were reflected in the fall in number of newly installed solar systems. The after-effects of the global economic crisis were noticed in 2010 when the solar thermal market dropped. In 2012 the solar thermal market recorded a further decrease of 16 per cent compared to 2011. This fall is justified due to falling PV prices and appealing incentives and compensation for electricity fed into the grid.

The most installed collector type in 2012 was the glazed flat-plate collector (95.8 % of newly installed collector area), followed by the vacuum collector (2.7%), unglazed flat-plate collector - swimming absorber (1.1%) and air collector (0.4%) (Biermayr et al. 2013).

In year 2012, the area of 4,929,657 m² of thermal solar collectors were in operation in Austria, which represents a total capacity of 3,451 MW_{th}. Glazed flat-plate collectors were the most common type (4,289,605 m² and 3.003 MW_{th}), followed by unglazed flat-plate collectors (558,601 m² and 391 MW_{th}) and evacuated tube collectors (79,542 m² and 56 MW), and the least air collectors (1,908 m² and 1 MW_{th} (Biermayr et al. 2013).

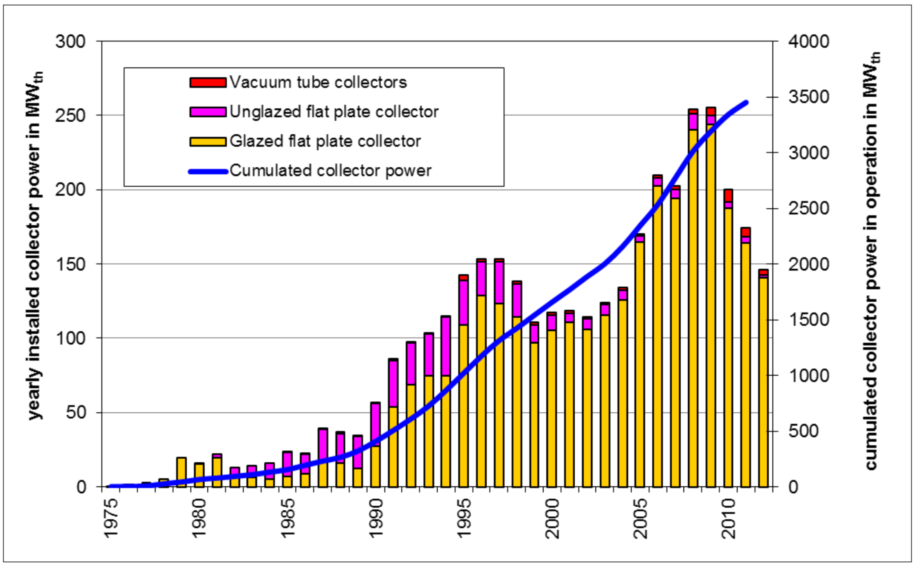

Figure 9 Market development of solar thermal collectors in Austria until 2012 (Source: Biermayr et al. 2011)

It should be emphasised that the Austrian solar thermal market is the 8th largest worldwide. If the number of collectors is compared with the population, then Austria is number three worldwide. Within Europe, Austria is second in terms of installed solar systems. Austria is one of the world's leader in installing and using the solar thermal energy. Compared with the 1980s, when solar thermal systems were strictly used for heating water in single family homes, technological developments mean that we now use them not only for warm water but also for space heating in single family homes and in multiple dwellings and 5 per cent of the area of newly installed collectors is used by tourist facilities such as hotels. The tendency to install solar combi-systems for warm water and space heating is also growing (Biermayr et al. 2013).

Compared with other countries, the levels of use of domestic hot water (DHW) systems for single family houses and solar combi-systems for single and multiple family houses in Austria shows a diversified market. 47 per cent of installed and in operation collector area (flat plate and vacuum collectors) are used for hot water in single family homes, 44 per cent as combi-systems for hot water and heating in single family and multifamily homes. Only 7 per cent of big systems are used for multifamily dwellings.

2.4 Building performance simulations

Building dynamic simulation has been available to building design engineers for some time. Energy performance simulation programs are powerful tools to study energy performance and thermal comfort during the building's life-cycle. Today, numerous such tools are available and they differ in many ways: in their thermodynamic models, their graphical user interfaces, their purpose of use, their life-cycle applicability, and their ability to exchange data with other software applications. Two types of software tools are being used nowadays: design tools, which are focusing in sizing HVAC equipment and simulation tools, which predict the energy performance of the building.

3 METHODOLOGY

3.1 Overview

This master thesis examines the calculated energy demand for a multi-family dwelling and, in further research, evaluates the total energy provided by applied solar systems. For this purpose a 3D model was developed in Tas, a building modelling and simulation tool. Application of such models can help understanding the energy performance of buildings as well as predict the behaviour of applied systems. Three different retrofit scenarios were simulated in terms of building's heating demand. The hot water demand was calculated according to standardized values (Eder et al. 1999). The electricity consumption was assumed by the *Statistik Austria* evaluation results. Further, the building's total energy demand was compared to the supplied energy from the solar systems.

Two cases were examined. Case 1 deals with the supply of the solar thermal system for domestic hot water and heating with the supply of the photovoltaic system for the electricity. Case 2 examines the supply for the domestic hot water and electricity. As final analysis a life cycle cost calculation was carried out with several different variations.

The following chapters describe the approach, from the geometrical compilation and simulation up to the calculation of the final energy demand. The information required for calculating hot water and electricity demand and other relevant parameters came from such sources as *Statistik Austria*, the *Austrian Standards* (ÖNorm, OIB) and further literature. In the simulations there are parameters which stay constant and which are adjustable. Table 3 you can see all parameters used in the simulation performances divided into constant and variable parameters.

Table 3 Fixed and variable input parameters used in the simulations

Input parameter	Constant parameter	Variable parameter
Location	x	
Weather data	x	
Purpose of use	x	
Number of users	x	
Construction		x
Internal gains	x	
DHW demand	x	
Electricity demand	x	
Panel options		x
Storage options		x

3.2 The case study building

3.2.1 Location

The building is located in the 16th district (Ottakring) within Vienna in Austria. This district is located in the western part of Vienna (Figure 10). “The buildings vary considerably in style. The working class settled around the industries and factories near the Gürtel (a substantial road around Vienna), resulting in a dense checkerboard pattern of residential housing. A little further up is a collection of villas around the Ottakring cemetery” (Wikipedia 2014). This part of the neighbourhood represents mainly buildings of the post war period. According to *Statistics Austria*, the current population growth in Ottakring is almost exclusively driven by migration from beyond Austria's borders.

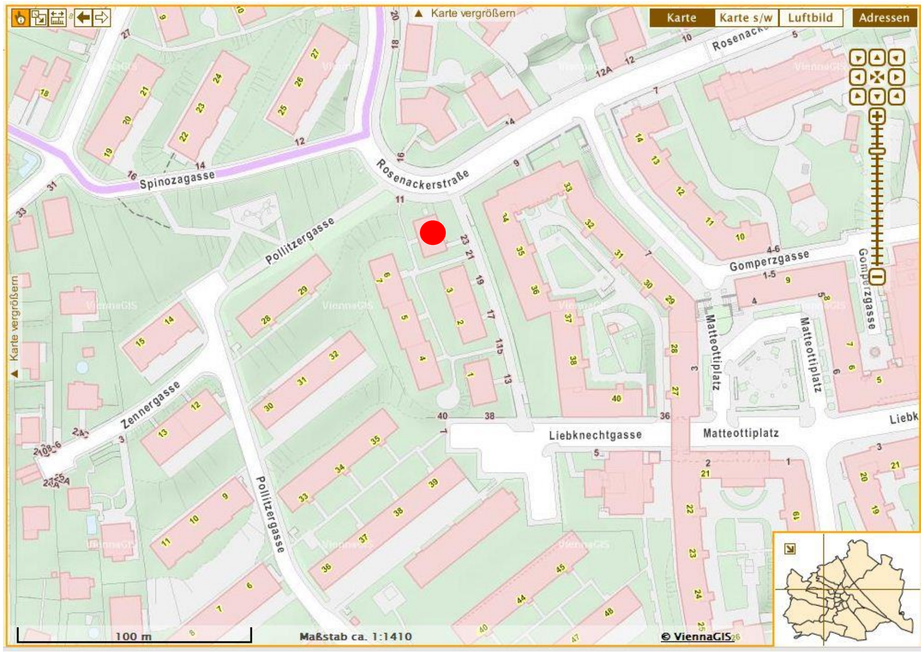

Figure 10 Site plan showing the location of the case study building (Source: GV 2013)

3.2.2 Building geometry and properties

The building is a typical post-war detached multi-family house built in the early 1950s. It is divided into three floors and a partly built-out roof floor. The typical floor has three flats types (Figure 11) which are accessible through a common staircase. The built-out roof space includes one flat. The remaining free area is unconditioned roof space (Figure 12). There is also an unheated basement floor which is not considered in the calculations of this study case simulations. The external dimensions of the building, according to the existing submission plans, are 16.04 x 10.26 m. The pitched roof is constructed with an angle of ca. 45 degrees (Figures 13-18). On the north-east side of the roof a dormer is illustrated in this model as roof window due to technical difficulties in modelling the dormer construction in the simulation software. The building construction elements and thermal properties of the building are discussed in later chapters. The basic building properties are listed in Table 4.

Table 4 Basic parameters of the study case building

Parameter	Value
Location	Karl-Metschl-Gasse/ Rosenackerstraße - Staircase 7, 1160 Vienna
Year of construction	1952
Number of flats	10
Net / gross area (m²)	774.58 / 968.23
Heated area net (m²)	449.86
Unheated area net (m²)	324.72
Dimensions (m)	16.04 x 10.26
Roof area (m²)	232
Window area (m²)	56.86
No. of inhabitants	20

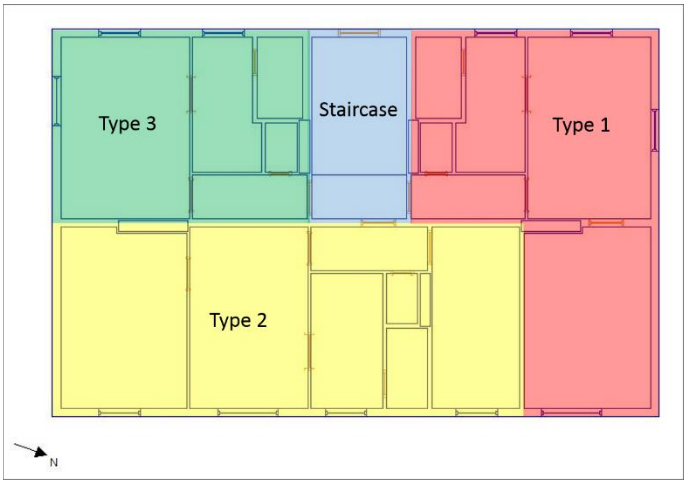

Figure 11 Typical floor plan

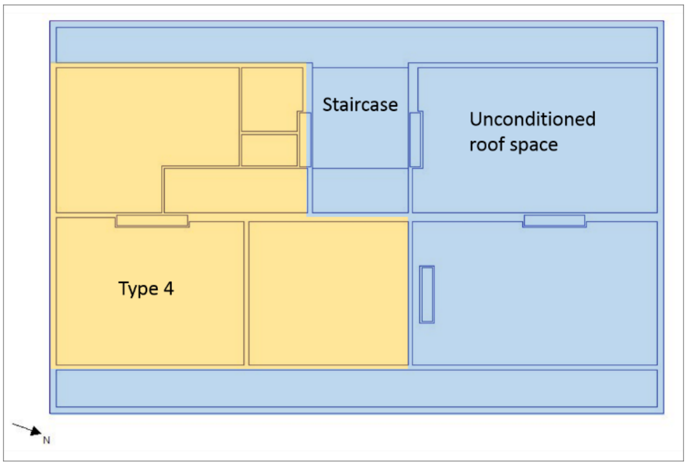

Figure 12 Roof floor plan

Figure 13 3D model (south-west facade)

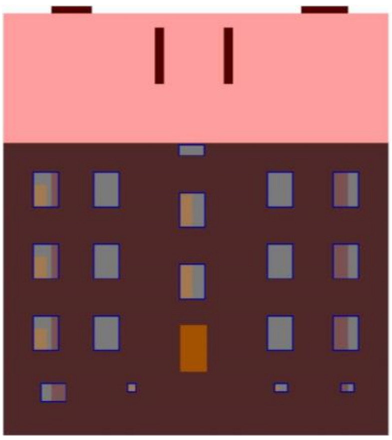

Figure 14 Front view (west facade)

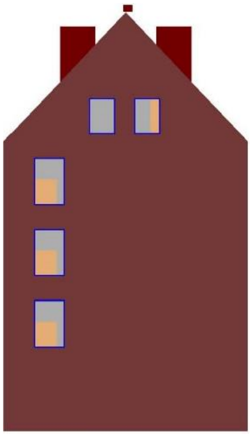

Figure 15 Front view: (south facade)

Figure 16 3D model (north-east facade)

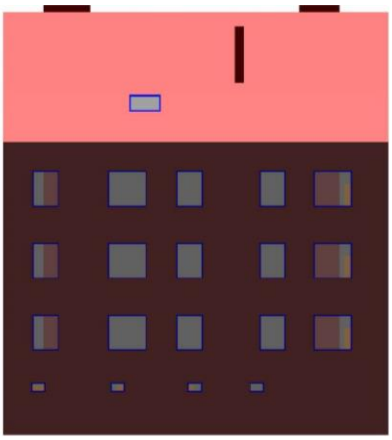

Figure 17 Front view: (east facade)

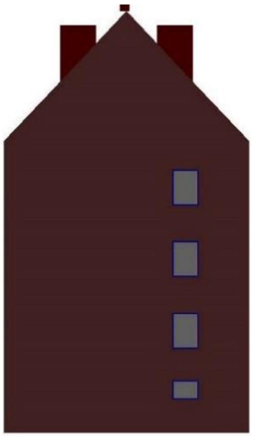

Figure 18 Front view: (north facade)

Figure 19 East facade

Figure 21 West facade

Figure 20 South facade

Figure 22 North facade

3.3 Applied evaluation methods and corresponding input data

3.3.1 Implemented performance simulation application

“Tas is a software tool which simulates the thermal performance of buildings. The main applications of the program are the assessment of environmental performance, prediction of energy consumption, plant sizing, analysis of energy conservation options and energy targeting. The fundamental approach adopted by EDSL (Environmental Design Solutions Limited) Tas is dynamically performed simulation. This technique traces the thermal state of the building through a series of hourly snapshots, providing the user with a detailed picture of the way the building will perform, not only under extreme design conditions, but throughout a typical year. This approach allows the influences of the numerous thermal processes occurring in the building, their timing, location and interaction, to be properly accounted for” (EDSL Tas 2012b).

The Tas software contains several programmes, which perform different functions:

3D Modeller is used to create the geometry of the building. “Tas 3D modeller allows you to trace out your floor plan using CAD drawings. As it isn’t a ‘volume modeller’ it allows quick adjustments to be made to the geometry. Building floors, building elements, windows, shades, and thermal zones are easily created and modified. Windows and shades can be grouped and applied to walls as one unit (only one window or shade type is needed for each different control strategy operating at the same time). Tas 3D modeller also allows the user to import gbXML files as well. The Tas gbXML import employs an intelligent healing feature that fills in the missing gaps in wall/ceilings etc. in the imported gbXML file” (EERE 2015). The finished model is then exported to be used further in the building simulator.

Building Simulator is linked to the *3D Modeller*. The fundamental approach of the *Building Simulator* is dynamic simulation. This technique traces the thermal state of the building through a series of hourly snapshots which provide the user with a detailed picture of the way the building will perform throughout a typical year. Input data such as weather data, constructional elements, and internal gains must be set for the calculation. The results consist of 8,760 data points for each variable that gives output such as heating and cooling loads, lighting, occupancy and equipment gains, surface temperatures and aperture data. After all the input data has been defined, the dynamic simulation can be executed and the results viewed in the *Results Viewer*.

Results Viewer is the part of Tas Building Designer used to display data stored in Tas Simulation Data (TSD) files. “The Tas Results Viewer allows the user to display results in tabular, graphical, or 3D. The 3D view superimposes the chosen data onto the selected building geometry allowing to step through hour by hour looking at the 3D model analysing anything from internal dry bulb temperature, internal solar radiation, aperture flow or any other data output” (EERE 2015).

Macros can be used to extract results such as the solar gain output from the solar plants and to display them in tabular or graphical form. The solar hot water (SHW) and photovoltaic (PV) Macro can be used to calculate the amount of hot water and electricity that could be generated by solar panels placed on a building. The macro calculates the output based on the amount of solar gain incident on the solar panel and the solar panel’s characteristics.

“Solar radiation absorbed, reflected and transmitted by each element of the building is computed from solar data on the weather file. The calculation entails resolving the radiation into direct and diffuse components and calculating the incident fluxes using knowledge of the sun’s position and empirical models of sky radiation. Absorption, reflection and transmission are then computed from the thermo-physical properties of the building elements. External shading and the tracking of sun patches around room surfaces may be included at the user's option” (EDSL Tas 2012b).

The SHW Macro uses several parameters to generate the output results:

- Maximum efficiency when delta T is zero
- First and second order heat loss coefficient
- Heat exchanger efficiency
- Storage volume and losses
- Pump power

The output of SHW Macro gives results for all applied elements for each hour of the year. The results are subdivided in several outputs: the surface output, total energy produced, building hot water demand, total energy utilized and finally energy stored in tank (EDSL Tas 2012b).

The PV macro requires following input:

- Efficiency of the PV array
- Inverter efficiency
- Environmental factors

The output of PV Macro gives results for all applied elements for each hour of the year. The results are subdivided in several outputs: PV surface output and building total.

3.3.2 Developing the geometry model

In order to perform thermal calculations a building model has to be designed into the *3D Modeller*. The original final plans provided the basis for the input of the geometry. In addition to such geometrical settings as orientation (north angle); latitude, longitude and time zone parameters can also be entered and used for shadow calculations. Tas reads these values from the imported weather file.

The *3D Modeller* works with simple geometrical forms. Freeform surfaces and complex forms are simplified. In the study case building the existing roof dormer was simplified in form of a roof window.

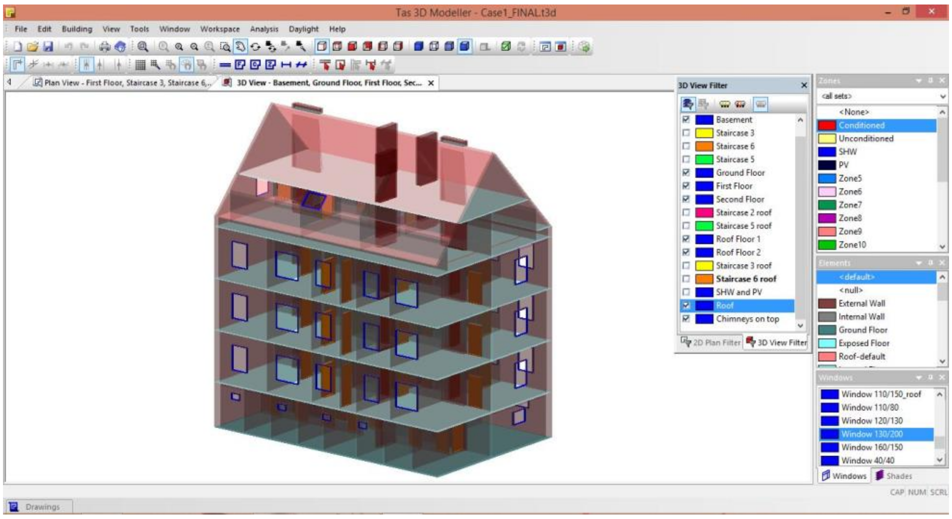

Figure 23 Transparent view of the 3D model in the Tas 3D Modeller

3.3.3 Weather Data

EDSL Tas Engineering gives access to over 2,500 recorded weather sites worldwide. The data consists of hourly values for solar, temperature, humidity and wind speed and direction (Table 5).

Table 5 Site parameters for the specific location (Source: EDSL Tas 2012a)

Longitude	Latitude	Time Zone	Ground temp.	Altitude	Outside temp.	Global radiation
48,25 °E	16,37 °N	UTC +1	12.9 °C	251 m	10.20 °C	136,36 $W.m^{-2}$

The weather file consists about 8,760 sets of hourly values of seven different variables:

- Global Radiation ($W.m^{-2}$) — Total solar radiation intensity on a horizontal plane.
- Diffuse Radiation ($W.m^{-2}$) — Diffuse sky radiation intensity on a horizontal plane.
- Cloud Cover (0-1) — A number varying from 0 for a clear sky to 1 for overcast conditions. This quantity is used to estimate long wave sky radiation during simulation.
- Dry Bulb Temp. (C) — The dry-bulb temperature as measured in a Stephenson screen.
- Relative Humidity (%) — The relative humidity as measured in a Stephenson screen.
- Wind Speed (m/s) — The wind speed measured at a height of 10 meters above the ground
- Wind Direction (DegEofN) — The direction from which the wind blows (degrees east of north).

“Many calculations for solar thermal energy systems require a separation of direct and diffuse irradiance because collectors react differently to each type. In general, the diffuse irradiation component is larger than the direct component in milder, cloudier climates; whereas in sunnier climates, nearer the equator, the direct irradiation component predominates. Nearer the poles there is a large difference between winter and summer direct irradiation.” (Laughton 2010). The monthly values of direct and diffuse solar radiation for the chosen location are shown in the following graph (Figure 24).

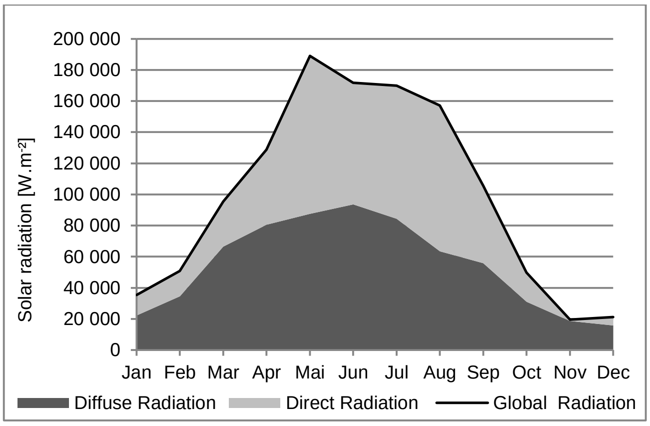

Figure 24 Direct and diffuse solar radiation from the Vienna weather file W.m^{-2}

3.3.4 Construction components

Due to the fact that the examined building dates from the 1950s, there is no precise information on the structure of the constructional components. In order to achieve realistic values, a manual for definition of external components (OPTIMUS) was used as guideline to assign the construction elements. For such buildings where no U-values are specified, the heat transfer coefficients from the *OIB Guideline - Energy performance of buildings* were applied (Table 7). The thermal retrofit is pursued in terms of applying the appropriate insulation to the thermal building envelope according to the Austrian standards (Table 8) and the Passive House standard (Table 6). All opaque building components of the exterior envelope of the Passive House must be very well-insulated (250 to 400 mm) with a heat transfer coefficient (U-value) of 0.15 $W.m^{-2}K$ at the most and the window frames must be well insulated and fitted with low-e glazing. This means an U-value of 0.80 $W.m^{-2}K$ or less, with g-values around 50 per cent (Table 6). The Space Heating Energy Demand should not exceed 15 kWh per square meter of net living space (treated floor area) per year.

Table 6 Passive House requirements for the external constructions and construction exposed to unconditioned spaces (Source: IG Passivhaus Tirol 2014)

Building Element	U-value [$W.m^{-2}K$]
Opaque constructions (walls, roofs, basement ceilings…)	0.1 – 0.2
Windows	0.8

Table 7 U-values (W.m⁻²K) of: BC=basement ceiling; UC=upper ceiling; EW=external wall; R=roof surfaces; W=window; G=g-value of glass in per cent; ED=external door; SFH=single family house; MFH=multifamily house (Source: OIB 2011a)

Epoch / Building type	BC	UC	EW	R	W	G	ED
Before 1900 SFH	1.25	0.75	1.55	1.30	2.50	0.67	2.50
Before 1900 MFH	1.25	0.75	1.55	1.30	2.50	0.67	2.50
From 1900 SFH	1.20	1.20	2.00	0.60	2.50	0.67	2.50
From 1900 MFH	1.20	1.20	1.50	0.60	2.50	0.67	2.50
From 1945 SFH	1.95	1.35	1.75	1.30	2.50	0.67	2.50
From 1945 MFH	1.10	1.35	1.30	1.30	2.50	0.67	2.50
From 1960 SFH	1.35	0.55	1.20	0.55	3.00	0.67	2.50
From 1960 MFH	1.35	0.55	1.20	0.55	3.00	0.67	2.50
Modular construction	1.10	1.05	1.15	0.45	2.50	0.67	2.50
Industrialised construction	0.85	1.00	0.70	0.45	3.00	0.67	2.50

Table 8 Selected building elements with corresponding U-value requirements according the Austrian standards (Source: OIB 2011b)

Building element	U-value [W.m⁻²K]
External walls	0.35
Walls to unheated or non-developed roof spaces	0.35
Walls to unheated or frost-affected parts of the building (excluding attics)	0.60
Walls in contact with the earth	0.40
Windows and doors in residential buildings to outside air	1.40
Other windows, French doors and vertical transparent components to outside air, glazed or unglazed exterior doors	1.70
Roof windows to outside air	1.70
Ceilings to outside air, to roof spaces (ventilated or non-insulated) and above passages as well as the roof sloping to the outside	0.20
Ceilings to unheated parts of the building	0.40
Floors in contact with the earth	0.40

3.3.5 Zoning

“A zone is defined as a region of the building in which the air temperature and humidity are assumed to be uniform. A zone may be a single space, part of a space or a collection of spaces” (EDSL Tas 2012b). For the calculation of energy consumption it may be necessary to subdivide the building into different calculation zones. The respective calculation zones arise from the particular uses for residential and non-residential buildings in accordance with the user profiles set out in *ÖNORM B 8110-5 – Thermal insulation in building construction Part 5 Model of climate and user profiles*. The total energy consumption of the building is derived from the sum of the energy requirements of all user zones.

A zone includes rooms or units within the conditioned floor area of a building, which are characterized by consistent use requirements (temperature, ventilation and lighting) with similar boundary conditions. Once it is established that a zone is to be conditioned (heating, cooling, humidification, ventilation), it is considered and calculated as ‘conditioned space’. Unconditioned spaces or areas are included in the calculations only due to their influence over neighbouring zones (heat flow through transmission) and must be clearly marked (OIB 2011a).

When applying a zone to a space, the assumption is that the enclosed volume of air is homogenous. In other words, the model will assume that within the zone, the air can mix freely and this will result in an average zone temperature. In this case each flat was set as one zone assuming that throughout one flat the temperature is homogenous but not necessarily all over the floor.

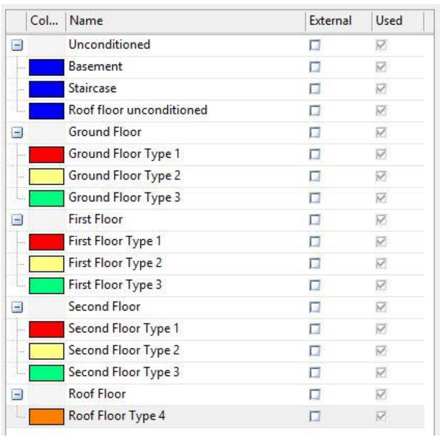

Figure 25 Zone groups applied to the study case building

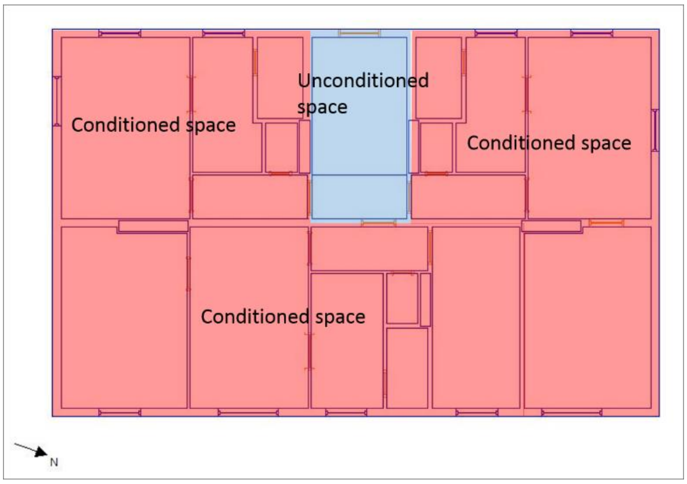

Figure 26 Conditioned and unconditioned zones – typical floor plan

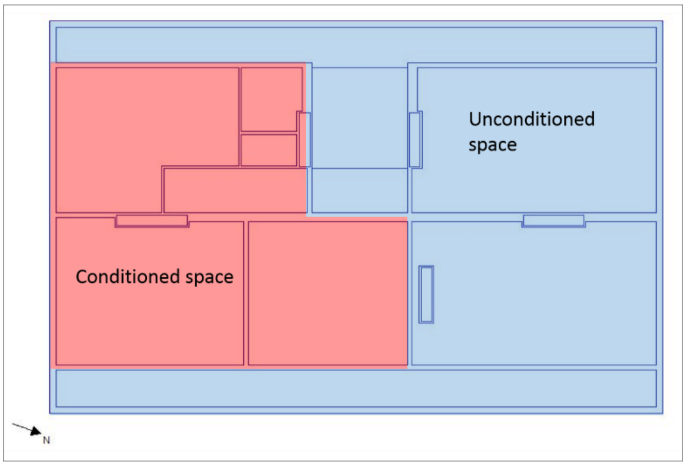

Figure 27 Conditioned and unconditioned zones – roof floor plan

3.3.6 Internal conditions

The internal conditions are important parameters for the calculations for a building and can have meaningful effects on the results. They are a compound of several preferences such as the specification of environmental control, incidental gains, infiltration and ventilation. These parameters are described below in more detail.

“Solar radiation absorbed, reflected and transmitted by each element of the building is computed from solar data on the weather file. The calculation entails resolving the radiation into direct and diffuse components and calculating the incident fluxes using knowledge of sun position and empirical models of sky radiation. Absorption, reflection and transmission are then computed from the thermo-physical properties of the building elements. The option exists to model external shading and the tracking of sun patches around room surfaces if required. Solar radiation entering a zone through transparent building components falls on internal surfaces, where it may be absorbed, reflected or transmitted depending on the surfaces' properties. Distribution of reflected and transmitted solar radiation continues until all the radiation has been accounted for" (EDSL Tas 2012b).

3.3.6.1 Internal gains

Internal gains are caused by the thermal energy emitted by people and equipment in the building (Figure 28). The gains are expressed in Watts per square metre of floor area. Depending on the number of people and activities and the use of space, gains are higher or lower (e.g. generally higher in office buildings with lots of equipment and staff). Internal gains are composed of the following fractional values:

- Occupant-related heat gain
- Equipment-related heat gain
- Lighting-related heat gain

The Austrian Standard *ÖNORM B 8110 – 5 Thermal insulation in building construction Part 5 Model of climate and user profiles* regulates values for internal gains by building type as shown in Table 9. For single and multiple dwellings this value is 3.75 W.m^{-2}.

Table 9 Internal gains according to the Austrian Standards (Source: ÖNORM B 8110 – 5: 2010)

Internal heat gains in W.m^{-2}			
Single family/Multifamily dwellings	3.75	Guesthouses	3.75
Office buildings	3.75	Hotels	7.5
Kindergartens	3.75	Restaurants	7.5
Secondary schools	7.5	Event spaces	7.5
Hospitals	7.5	Sports facilities	7.5
Care homes	3.75	Retail facilities	3.75

People and electrical equipment in buildings emit heat. These internal heat gains must be included in energy calculations in the building or zone in order to determine the net heating or cooling load. The heat gains in residential buildings are assumed to be permanent, which means around the clock.

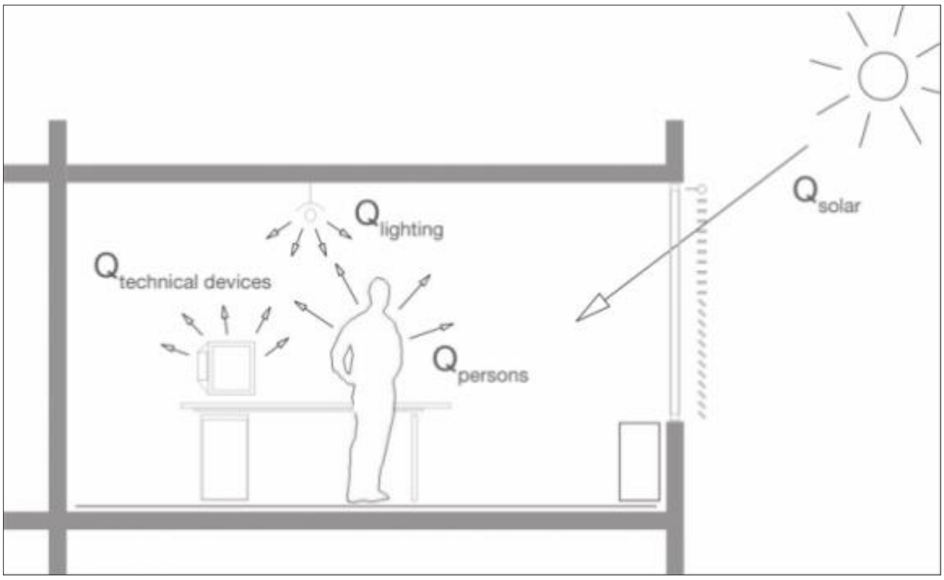

Figure 28 Internal heat gains caused by lighting, occupancy and technical devices (Source: EDUCATE 2012)

The value of 3.75 W.m^{-2} is divided between the three already mentioned categories of internal gains in conditioned and unconditioned (staircase, basement, roof space etc.) zones. The following table (Table 10) shows this division.

Table 10 Internal conditions divided between the three categories used in the simulation programme Tas

Internal Gain	Conditioned zone [W.m^{-2}]	Unconditioned zone [W.m^{-2}]
Lighting	1.00	1.00
Occupancy	1.00	-
Equipment	1.75	-

3.3.6.2 Air exchange rate

Infiltration is the uncontrolled passage of air into buildings through such leaks in the building envelope as cracks, windows, doors etc. This occurrence is defined in air exchange rate which records the number of interior volume air changes that occur per hour. The air exchange rate is also known as air changes per hour (ACHs). The Austrian Standard ÖNORM B 8110-5 regulates the air exchange rate in residential buildings as 0.4 h^{-1} for conditioned spaces. Unconditioned spaces are defined with the same values of conditioned area. In terms of airtightness in a Passive House, a maximum of 0.6 air changes per hour at 50 Pascals pressure must be met.

3.3.6.3 Room conditioning parameters

According to the Austrian Standard ÖNORM B 8110-5 for the determination of heating demand, a minimum room temperature of around 20°C is standard. Therefore the thermostat is set for a lower limit of 20°C, which means that heating is provided to the space when the room temperature decreases below the set temperature. There is no thermostat determination for unconditioned room spaces.

3.3.6.4 Hot water demand (HWD)

Hot water demand can vary not only as a result of building type (e.g. residential house, restaurant, hotel or office), apartment size and number of inhabitants, but also as a result of living standard, inhabitant’s age, occupation and season, etc.

Measurements of the required capacity of water heating systems usually assume a cold water temperature of 10°C as set out in the Austrian Standards. Warm water temperatures vary depending on the purpose for which the water will be used. Typical values are 45°C for sinks, showers and bathtubs and 60°C for cooking (Eder et al. 1999). Table 11 shows average daily water consumption in litres at a temperature of 60°C and the energy used in kWh. Calculations for this study case were based on the category “multi-family dwelling” and high general consumption of 50 l/d/p or 2.78 kWh/d/p.

The Macro tool calculates hot water consumption according to the set up schedule in the “Building Simulator”. The Tas schedule is a time-series of 0’s and 1’s set for each hour of the day. The numbers specify when the gain is using its value and its setback value. When the hourly value is set to 1, a gain will use the value. When the value is 0, a gain is using the setback value. More about the hot water user profile is discussed in later chapters.

Table 11 Energy demand for hot water in family homes in litres and kWh per person (Source: Eder et al. 1999)

Building type	Purpose	DHW demand in l at 60 °C/d + kWh						
		Unit	Min [l]	kWh	Medium [l]	kWh	High [l]	kWh
Multifamily dwelling	Social	Person	20	1.11	30	1.67	40	2.23
	General	Person	30	1.67	40	2.23	50	2.78
	Upper	Person	40	2.23	50	2.78	70	3.90

3.4 Retrofit Scenarios

As mentioned in the previous chapters the building is a typical post-war detached multi-family house built in the early 1950s. The 50s are characterized by thrift, scarcity of materials and simple constructions. In the houses of that period, the outer walls have very small cross-sections with poor or no thermal insulation properties. The floor slabs are usually made of reinforced concrete, often with bonded screeds without further noise protection measures. The roof trusses have largely chemical wood protection and are sized very small. Most apartments have a built-in bathroom. The heating system still prevails individual heating. The apartment sizes are simple and sometimes cramped. The windows are made of wood with single glazing (BauNetz 2014).

For the calculations of thermal building performance the individual construction elements are in line with the *OPTIMUS - Guide to the specifications of the outside components*. A compilation of constructions used for this study is shown in the appendix. Three different scenarios were selected to illustrate the comparison of thermal improvement of the building (Figure 29).

The most cost-effective way to apply the solar thermal systems for domestic hot water and space heating is first to reduce space heating requirements before adding solar panels. Upgrading the thermal insulation is a necessary step. Once these improvements are made, solar water heating becomes the next biggest energy-saving measure.

Figure 29 Figurative display of the applied three retrofit scenarios on the study case building

3.4.1 Current State of the Building (Scenario 1)

The construction elements in first scenario (S1) are based on the default values from the year of construction (1952) according to the *OIB Guideline - Energy performance of buildings* (Table 12).

Table 12 Constructional elements and the U-values for Scenario 1

Construction	External Wall	Floor between basement and GF	Uppermost ceiling (to cold roof space)	Roof	Window	Door
U-value [W.m^{-2}K^{-1}]	1.73	0.86	1.17	1.45	1.36	1.70

3.4.2 First Step of Retrofit (Scenario 2)

The second scenario (S2) is based on the current Austrian Standard ÖNORM requirements according to the *OIB Guideline – Energy conservation and thermal protection* (Table 13).

Table 13 Constructional elements and the U-values for Scenario 2 according to ÖNORM

Construction	External Wall	Floor between basement and GF	Uppermost ceiling (to cold roof space)	Roof	Window	Door
U-value [W.m^{-2}K^{-1}]	0.33	0.37	0.38	0.18	1.36	1.70

3.4.3 Second Step of Retrofit (Scenario 3)

To improve the thermal situation of the building, a third scenario (S3) was applied. This involves improved construction components based on low energy and Passive House standard in terms of heating demand of not more than 15 kWh.m^{-2} per year. More details of the composition of all construction elements of each scenario can be found in the appendix.

Table 14 Constructional elements and the U-values for Scenario 3 according to Passive House Standards

Construction	External Wall	Floor between basement and GF	Uppermost ceiling (to cold roof space)	Roof	Window	Door
U-value [$W.m^{-2}K^{-1}$]	0.12	0.13	0.12	0.11	0.8	0.8

3.5 Solar Systems

The realization of a self-sufficient building requires the activation of renewable energy resources. This study examines the potentials of renewable solar energy systems on an existing multifamily building located in Vienna. Two solar systems were case of the research: solar thermal and the photovoltaic system. Because sun changes its position through the days and seasons, no single fixed position is perfect all day time. However there is usually one fixed angle which gives the optimum performance over a year. In case of the research example the building has a pitched roof with a defined angle of ca. 45° which predefines the positioning of the solar panels. Two study cases were studied. The first case (C1) implies three criteria: domestic hot water (DHW) demand, heating demand and electricity consumption. The second case (C2) studies DHW demand without the heating component and electricity consumption. The solar panel application on the wall surfaces was considered but due to the excessive shading of surrounding buildings not further pursued.

3.5.1 Solar Thermal Systems

Solar heat defines the conversion from the solar radiation into heat. Solar thermal systems use the solar energy to support the domestic hot water and space heating demand. The concept of all thermal systems is similar. The main part is the solar collector and its absorber which absorbs the sun light and transfers it to heat via a fluid which is circulating through pipes. In order to lose as little heat as possible the collector is insulated from the back and the sides. The heated fluid ends up into a storage tank filled with water. Via a heat exchanger the water in the tank is heated up and runs directly into the hot water system and/ or heating system. With solar space heating the demand for heat is quite seasonal, whereas domestic hot water is required all year round. When solar irradiation is insufficient, a back-up source switches in to achieve the desired temperature (Figure 30). When a system is oversized it cannot utilize all the existing solar irradiation.

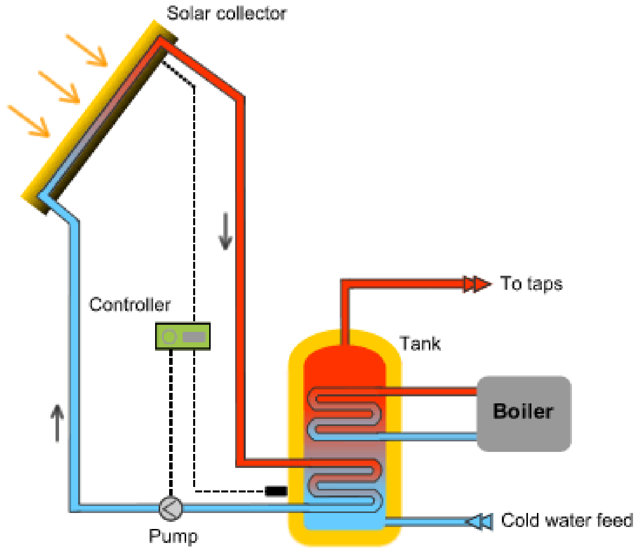

Figure 30 Typical solar thermal system for domestic hot water supply and heating support (Source: Daviddarling 2014)

3.5.1.1 Solar panel input parameters

For demonstrative results of the performed simulations for the solar thermal system actual manufacturer's specification was used (Table 16). The efficiency and heat loss coefficient parameters have been taken from the manufacturer's specification. The efficiency of the heat exchanger and the storage losses and pump power were set by programme default. The efficiency factor and the efficiency curve is defined with three parameters: η_0, a_1, a_2. The optical efficiency η_0 describes how much of sunlight the absorber is transferring into heat. Depending on the type of collector optical efficiency is between 70 - 90 per cent. The two loss coefficients a_1, a_2 indicate the heat losses in the collector. The hotter the collector, the higher the heat losses. The most important property in terms of the results of the solar thermal calculations is solar reflectance. The lower the solar reflectance, the more the solar gain is absorbed.

Table 15 Solar collector parameters as a basis for the solar thermal calculations

Technical parameters	Symbol [Unit]	Value
Collector aperture area	A [m²]	2.29
Max. efficiency when delta T is zero	η_0 [-]	0.8
First order heat loss coefficient	a_1 [W.m^{-2} K]	3.0
Second order heat loss coefficient	a_2 [W.m^{-2} K²]	0.008

3.5.1.2 Dimensioning the storage tank

The supply of solar energy is variable and is not simultaneous with periods of high demand for heating energy. Beside the collectors, the hot water storage tank is another significant component of a solar plant system, because correct dimensioning is crucial if the solar coverage ratio is to be met. The most generally accepted tanks for warm water solar facilities are standing slim pressure tanks with a proportion of 2.5:1 (height:diameter). This shape ensures a distinctive layering of warm water. Storage tanks are made from either stove-enamelled steel, stainless steel or steel with a plastic coating.

“If the effective volume is too small or large, more back-up energy will be required and there may be a risk of overheating. The required total effective volume should represent between once or twice the average daily hot water consumption, dependent on the climate, collector performance and collector area” (Laughton 2010).

Typically, a storage volume between 50 and 100 litres per square meter collector area is installed in solar thermal systems for domestic hot water and heating support (DSTTP 2010). To retain stored energy as long as possible, the storage tank must be adequately insulated. It is important to ensure that the insulation is applied to the storage tank without leaks. Heat loss from a storage tank increases in proportion with its surface area.

Table 16 Storage tank parameters as a basis for the solar thermal calculations

Technical parameters	Symbol [Unit]	Value
Storage volume (C1)	[l]	8,000
Storage volume (C2)	[l]	6,000
Storage losses	[kWh/l/day]	0.019

3.5.1.3 Other solar thermal system components

Table 17 Other solar thermal system parameters as a basis for the solar thermal calculations

Technical parameters	Symbol [Unit]	Value
Heat exchanger efficiency	[%]	40
Pump power	[W/l/hour per m² of A_{coll}]	5.50

3.5.2 Photovoltaic Systems

To meet the electricity demand of the studied building a photovoltaic system has been applied. The best efficiency is obtained with a southern orientation and an inclination of 30° from the horizontal. However, PV modules can face up to 45º east or west of true south without significantly decreasing their performance. Ideal aligned the plants with commercial module efficiencies achieve of about 11%, 130 kWh/(m².Pv.A). Nevertheless, the south vertical surfaces also bring about 80 kWh/(m².Pv.A). The following figure (Figure 31) shows the best efficiency of PV panels according to the inclination and orientation. In case of the study case building the pitched roof with a defined angle of ca. 45° predefines the positioning of the PV modules.

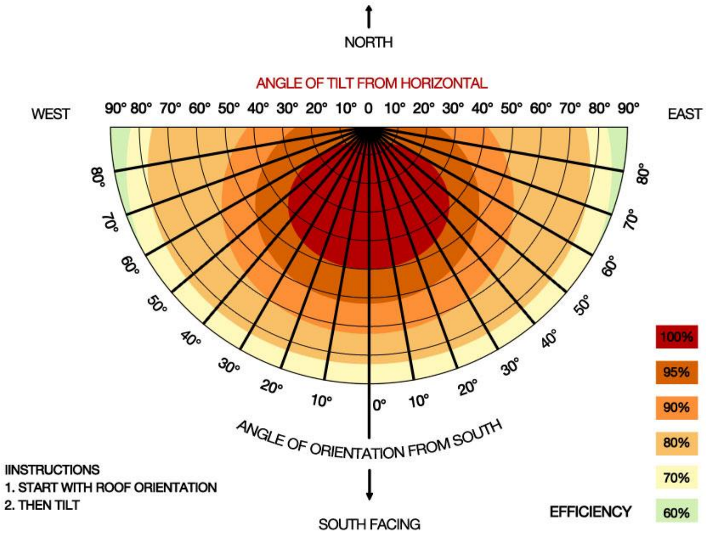

Figure 31 Solar orientation system showing best tilt and angle for placing the PV panels (Source: Evergreendeal 2014)

3.5.2.1 PV panel input parameters

PV modules are defined by their peak power output under standard test conditions (STC). These are when the light shining on them is 1kW per square metre, the temperature of the module 25 degrees Celsius and the air mass (AM) 1.5. EDSL Tas Macro gives the opportunity to set several parameters of the panel as well as the AC inverter. In Table 18 PV panel and inverter parameters as a basis for the PV calculations (EDSL TAS 2012a) the photovoltaic panel output is shown in W.m^{-2} which is produced by the PV array as a function of irradiance and the inverter AC output as a function of PV panel DC output. Further the PV panel power is reduced due to environmental factors (Table 19).

Table 18 PV panel and inverter parameters as a basis for the PV calculations (EDSL TAS 2012a)

Data point	PV panel parameters		Inverter parameters	
	Irradiance [kW.m^{-2}]	Array output [W.m^{-2}]	Total PV output [% of max]	Inverter efficiency [%]
1	0.1	6.670	0.0	0.0
2	0.2	15.560	2.5	35.0
3	0.4	31.110	5.0	70.0
4	0.5	40.000	10.0	85.0
5	0.6	48.890	20.0	89.0
6	0.8	66.670	30.0	93.0
7	1.0	82.220	100	93.0

Table 19 PV panel power reduction due to environmental factors (EDSL TAS 2012a)

Reduction due to...	Value [-]
Dirt (%)	7.0
Diodes and wiring (%)	3.0
Ageing (% reduction per year)	0.20
Panel age (years)	0.00
Total reduction due to age (%)	0.00

3.5.3 Case 1: Supply of domestic hot water, heating and electricity demand

The basic principle of this case is overall supply of hot water and heating demand as well reducing electricity consumption by generated power from the PV system. Figure 32 shows the distribution of solar collectors and photovoltaic modules on the roof. On the SW side of the pitched roof 36 solar collectors (light blue) were applied. On the NE side of the roof the area was covered with 49 photovoltaic modules (dark blue). Single panels were grouped in the *3D Modeller* as one area to simplify the designing and calculation process. The aperture area of a single panel was multiplied by number of 36 which represents the panel area without frame.

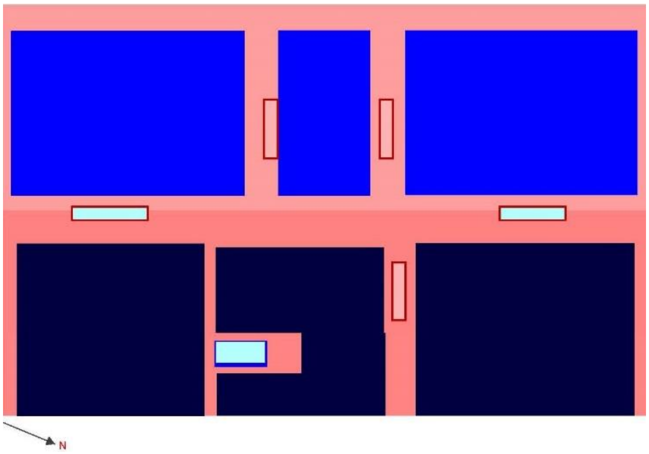

Figure 32 Solar thermal and photovoltaic panels distribution on the roof for Case 1

Table 20 General information of the solar and PV panels for Case 1

	Solar thermal	PV
Area [m²]	83.60	85.60
Orientation [-]	SW	NE
Tilt Angle [°]	45	45
Storage volume [l]	8,000	-

3.5.4 Case 2: Supply of domestic hot water and electricity demand

The second case studied the supply of DHW and the decrease of electricity consumption. For that purpose the solar thermal collector size was decreased (light blue on Figure 33) to cover solely domestic hot water needs. The remaining free area on the same roof was covered with additional PV modules (dark blue on Figure 33). The aim was not to create a surplus of the solar thermal system and to generate more electricity of the PV system which can be fed right away into the grid.

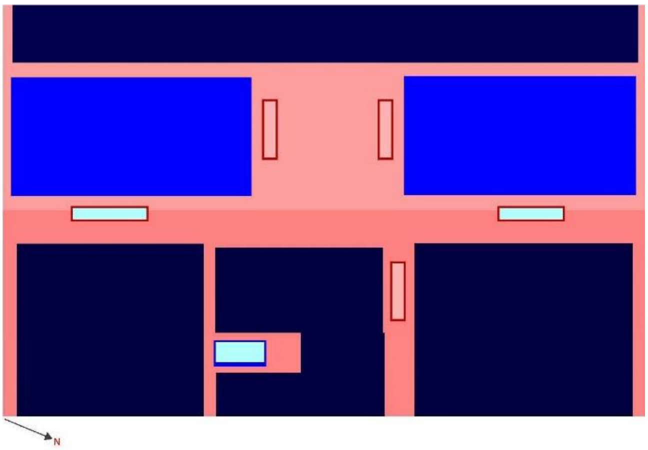

Figure 33 Solar thermal and photovoltaic panels distribution on the roof for Case 2

Table 21 General information of the solar and PV panels for Case 2

	Solar thermal	**PV**
Area [m²]	60.30	105.13
Orientation [-]	SW	NE, SW
Tilt Angle [°]	45	45
Storage volume [l]	6,000	-

3.6 Life Cycle Cost Assessment

3.6.1 General

"LCCA is a process of evaluating the economic performance of a building over its entire life. Sometimes known as 'whole cost accounting' or 'total cost of ownership', LCCA balances initial monetary investment with the long-term expense of owning and operating the building. LCCA estimates the total cost of the resulting building, from initial construction through operation and maintenance, for some portion of the life of the building. By comparing the life cycle costs of various design configurations, LCCA can explore trade-offs between low initial costs and long-term cost savings, identify the most cost-effective system for a given use, and determine how long it will take for a specific system to "pay back" its incremental cost." (Stanford University 2005).

3.6.2 Calculating Method

The building-related costs in the life cycle normally consist of all costs resulting from the planned or expected life of the building itself. They are usually calculated over the specified time period of 50 years. The life cycle cost calculations in this master thesis is based on the investment costs, the annual maintenance and repair costs as well as the operation (expected annual energy) costs. The LCC assessment is carried out according to DIN 276-1, with an impreciseness of +/- 10 per cent. This standard code covers the cost of the construction, reconstruction and modernization of buildings. The cost breakdown provides three levels of cost classification and is divided into seven cost categories:

- 100 Land
- 200 site infrastructure works
- 300 Building - Building construction
- 400 Building - Equipment
- 500 Outdoor Facilities
- 600 Equipment and art
- 700 additional building costs

For this purposes the CG 300 Building - Building construction and CG 400 Building – Equipment are considered for the cost calculations. For detailed structure of each cost group see appendix. In this cost calculation no maintenance costs occur concerning structural measures in the first 25 years. The renovation costs or further investments during the life cycle were not considered either, because the subsequent amortization calculation aims to measure the return of investment within the shortest life-time of construction components (<20 years). All costs are standard industry net prices. The calculated costs consider an average heat price including counter net price (excl. taxes) of about EUR 0.085/kWh and for the PV buyback price EUR 0.19/kWh. On the basis of these two cost factors, the total investment for each year per operating system was calculated. These values plus a rise in energy prices of 2.5 per cent as well as increased costs of maintenance and repair were linearly applied over the 20 years period.

Cost Group 300

This cost group covers all construction and supplies during the construction of the building, but without the technical equipment (Cost Group 400).

Cost Group 400

The CG 400 is structured particularly in the subsection sanitary (domestic hot water, drinking water supply lines, etc.) heating (district heating, solar panels, heat generation plants, etc.) power installations (PV, electric wiring for building services) building automation, control system facilities, technical systems and electrotechnical equipment including cabling. More details about the structure of the cost group 400 is shown in the appendix.

For this study case three options result from all the cases and scenarios:

Option I: no structural measures and thus investment according to CG 300

Option II: low energy standard with the associated retrofit of the facade, windows, doors and insulation

Option III: Passive House standard with the associated investment in the facade, windows, doors and insulation

3.6.3 Calculated options

The life cycle cost calculation contains seven different variants. Each variant is shown in Table 22.

Table 22 Overview of the different variations of the life cycle cost calculations

	Variant	CG300	CG400	S1	S2	S3	C1	C2
Option I	Variant 1	-	x	x	-	-	-	-
	Variant 2	-	x	x	-	-	x	-
	Variant 3	-	x	x	-	-	-	x
Option II	Variant 4	x	x	-	x	-	x	-
	Variant 5	x	x	-	x	-	-	x
Option III	Variant 6	x	x	-	-	x	x	-
	Variant 7	x	x	-	-	x	-	x

Following description gives an overview of each option in every variant.

CG 300 Cost group covering all structural costs of the building.

CG 400 Cost group covering costs of the technical equipment in the building.

S1 Scenario 1 represents the base case of the simulations in terms of the annual heating demand.

S2 Scenario 2 represents the first step of refurbishment according to the Austrian standards in terms of annual heating demand.

S3 Scenario 3 represents the second step of refurbishment according to the Passive House standards in terms of the annual heating demand.

C1 Case 1 represents the simulation of the solar systems with 83.60m² of solar collectors and 85.60m² of PV panels.

C2 Case 2 represents the simulation of the solar systems with 60.30m² of solar collectors and 105.13m² of PV panels.

4 RESULTS AND DISCUSSION

4.1 Overview

This chapter presents the simulation results performed with Tas software - building modelling and simulation tool. The results are divided into three main sections. Firstly the building's total energy demand is showed. This includes the hot water demand, heating demand and electricity consumption. The heating demand simulation results are presented for the three proposed scenarios of thermal refurbishment as described in chapter 3.4. Further the output of solar system calculations is presented. Finally, the system costs, operating and maintenance costs for seven different variants were estimated. For better comparison all results are presented as monthly values.

4.2 Building's Total Energy Demand

4.2.1 Hot Water Demand

In the theoretical calculation of the domestic hot water demand for the dynamic simulations, it was assumed that a constant volume was consumed in the study case building throughout the year. A usage group of general purpose and high consumption with the value of 50 litres per day and person was applied (Table 11). Children are considered as adults in this calculation. With an assumption of 20 inhabitants and a schedule with constant usage from 6am to 11pm the total hot water demand for the study case building sums up to ca. 57 kWh per day. Following figure (Figure 34) shows the hourly distribution of the building's hot water demand for the study case building.

Tas schedule is a time-series of 0's and 1's set for each hour of the day. The numbers specify when the gain is using its value and its setback value. Therefore the calculation of domestic hot water is based on the continuous value throughout the given hours.

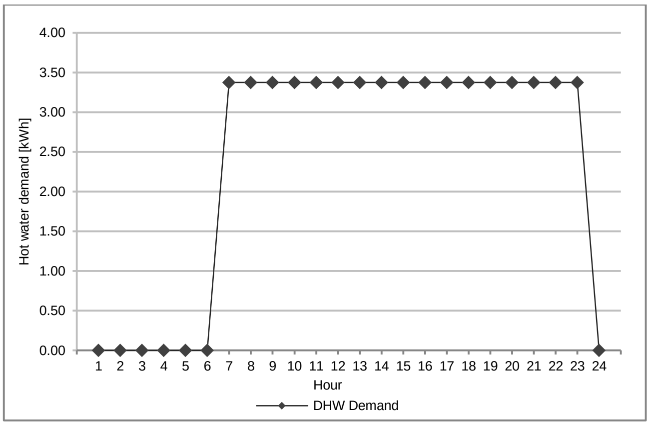

Figure 34 Domestic hot water daily user profile of the study case building (Source: EDSL Tas 2012a)

4.2.2 Heating Demand

This section of the chapter presents the heating demand simulation results for three proposed scenarios of thermal refurbishment. The results of dynamic simulated data for a year-long period contain sets of hourly data. These were summed in monthly and annual values as presented in the following graphs and tables in this chapter.

The following is a brief guide on the developed scenario cases: Scenario 1 (S1) represents current state of the building with the building envelope thermal quality of the year of construction. Scenario 2 (S2) represents improvement of the building envelope according to Austrian Standards. Scenario 3 (S3) represents improvement of the building envelope according to Passive House Standards.

Both scenarios of thermal refurbishment, Scenario 2 and Scenario 3, can make a distinct contribution to the energy savings in terms of heating demand. Scenario 2 shows ca. 79 per cent savings, and Scenario 3 ca. 90 per cent savings compared to the base case scenario (S1).

Table 23 Results of the monthly heating demand simulation for the case study building for the three proposed scenarios in kWh

Month	Heating Demand [kWh]		
	S1	**S2**	**S3**
Jan	14,705	3,329	1,401
Feb	15,636	3,465	1,737
Mar	10,571	1,759	891
Apr	4,274	374	105
May	2	0	0
Jun	0	0	0
Jul	0	0	0
Aug	18	0	0
Sep	401	0	0
Oct	5,495	832	3
Nov	15,831	3,521	1,213
Dec	14,570	3,291	1,312
Annual	**81,502**	**16,570**	**6,661**

The results from previous table are also illustrated in Figure 35. The obvious expectations that a Passive House standard building will have the lowest heating demand is proofed in the following figure. From the graph there is a clear pattern in all three scenarios. In the winter months there is the highest heating demand. Whereas Scenario 1 requires heating energy in the months of April and October, S2 and S3 require very little heating energy during these months.

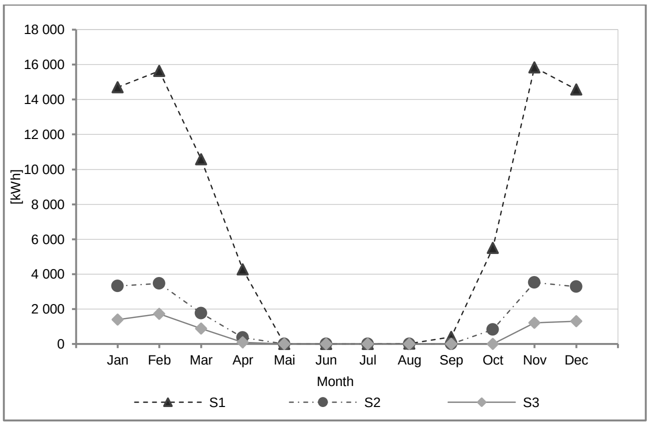

Figure 35 Monthly results of the heating demand simulations for all three studied scenarios in kWh

4.2.3 Electricity Demand

The basis for the electricity demand was taken from the research made by Statistik Austria. The records were collected for the period 2003 to 2010. Time series for the detailed end use of electricity in private households were generated. The total annual electricity consumption in 2010 was 3.055 kWh per household or 1.874 kWh per person. An overview of the statistic results at the household level and per person depending on the number of dwellings in residential buildings is shown in appendix.

The Institute of Power Systems and Energy Economics at the Technical University of Vienna published a study of user behaviour and patterns of electricity use for energy savings. Fifty one homes were examined considering house type, location, floor area, household size and several other factors. From the measurement results a daily user behaviour was generated for the weekdays and weekends on an hourly basis. The statistics values were implemented to the user profile and is shown in figure below (Figure 36).

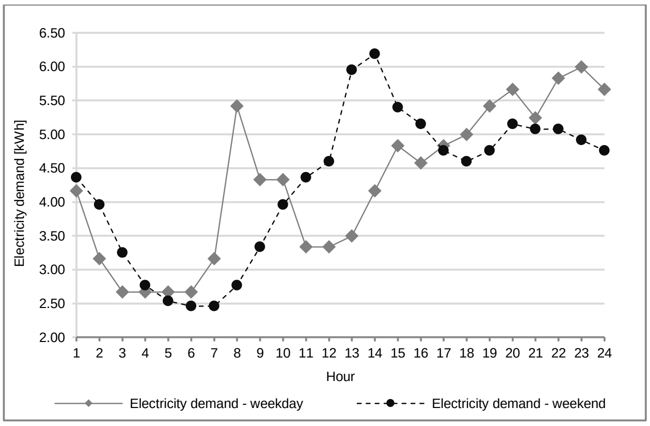

Figure 36 Daily user profile of the electricity demand on weekdays and at weekends in kWh (Source: Ghaemi and Brauner 2009)

4.3 Solar System Results

This chapter shows the output results of the heating demand calculations as well as the output of the two applied solar systems - the solar thermal and photovoltaic system. Two cases were examined. In the first phase both the heating and hot water demand was aimed to be covered by the solar thermal system. The rest of the roof area was used for the PV panels. Second phase was focusing to cover the domestic hot water demand with the solar thermal system. On the remaining free roof area additional PV panels were applied to increase the power output.

4.3.1 Case 1: Supply of DHW, Heating and Electricity Demand

On the basis of weather data, the collector yield is calculated for each of the two solar systems. The software has calculated the data hourly which were summed to monthly and annual total. The yearly sum of irradiation of the roof collector field is 95,520 $kWh.a^{-1}$. Total energy produced for 80m^2 collector area comes up to 21,459 $kWh.a^{-1}$. Due to thermal and optical losses of the solar panels, the pipes and storage, solar heated water energy utilised by the occupants of the building amounts to 15,279 $kWh.a^{-1}$.

The heating and hot water demand are summed up and presented as a total energy demand. The three scenarios (Figure 37) of refurbishment show distinctive differences in the heating energy demand. With the increased solar thermal collector area the demand in winter months can't still be achieved whereby in the summer months a surplus is produced. This surplus is actually lost energy which is not efficient.

Below in Figure 5.3 this amount of energy generated by solar energy is shown. In April and May is an increase in yield, due to favourable angle of incidence of the sun visible. The amount of heat energy rises in June and from July barely even less again. However, a thermal energy output is possible even in the winter months.

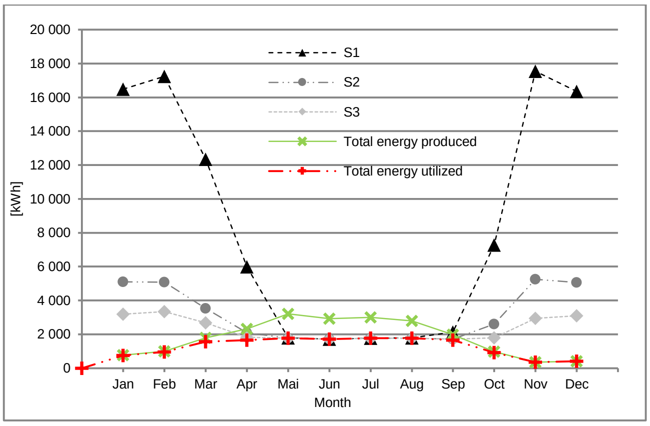

Figure 37 Total energy demand for all 3 scenarios compared with the solar thermal output in kWh

The output of the photovoltaic modules is simulated using weather data. The hourly calculated data result in a total output of 4,588 kWh/a. This is only a fraction of the total electricity demand (Figure 38). In this case a grid-connected photovoltaic power system is most sufficient and will reduce the power bill as it is possible to sell electricity produced to the local electricity supplier.

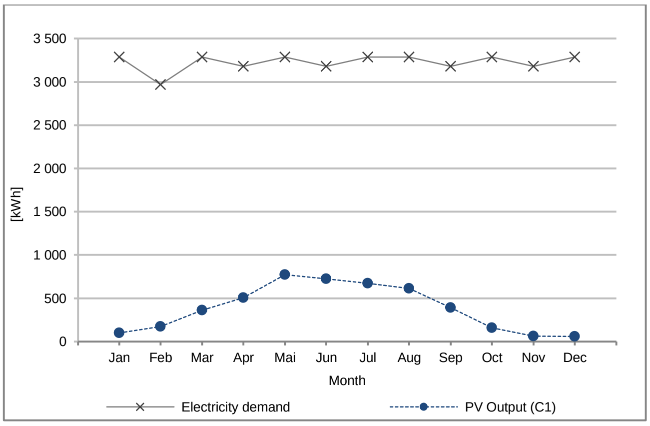

Figure 38 Case 1: Photovoltaic output and the electricity demand

Following graphs show the days of highest and lowest PV output. On day 167 ca. 39 per cent of electricity demand can be covered by the PV system. On day 356 only 3 per cent can be generated from the PV system (Figure 40). Figure 41 shows the PV output subdivided and categorized by the amount of kWh and the number of days reaching this amount. In this case for 45 per cent of the year the output is less than 10 kWh. At only 42 days in a year, the PV output makes more than 30 kWh.

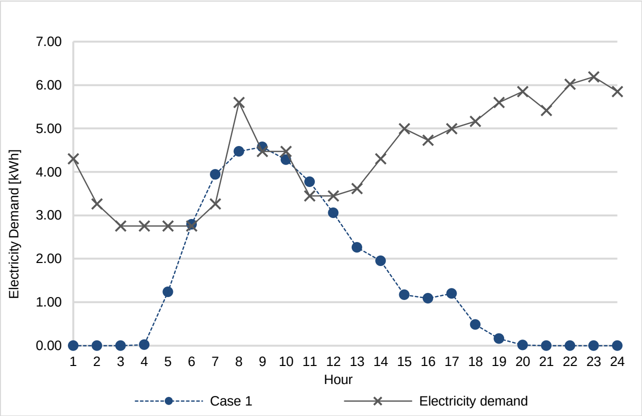

Figure 39 Daily profile of electricity demand in comparison to the highest PV output on day 167 for Case 1

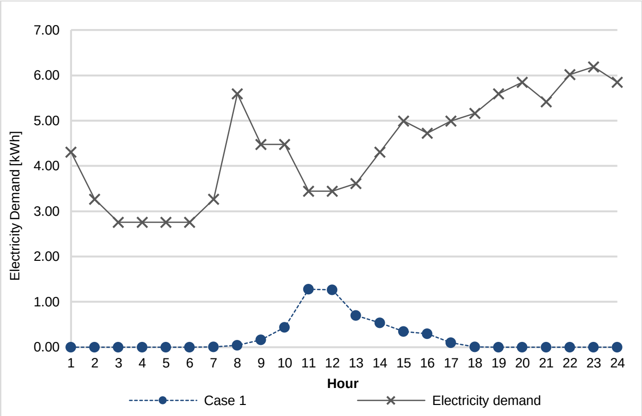

Figure 40 Daily profile of electricity demand in comparison to the lowest PV output on day 356 for Case 1

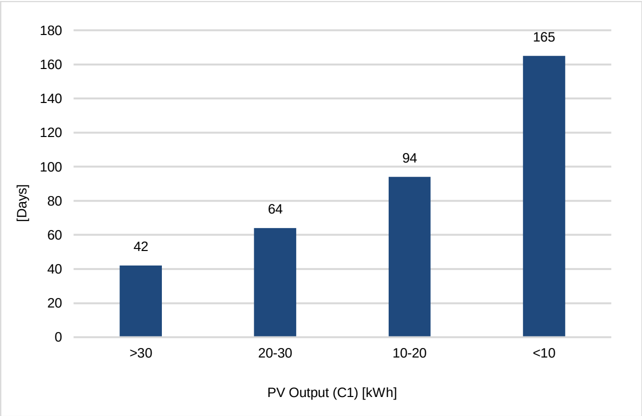

Figure 41 Number of days of the annual PV output categorized by the amount of its output for Case 1

4.3.2 Case 2: Supply of DHW and Electricity Demand

The second case focuses on the supply for domestic hot water and electricity. The solar thermal panel size was decreased in order not to produce a surplus in summer (Figure 42). The remaining free roof area was covered with additional PV modules (see chapter 3.5.4). In the period from Mai to July the hot water demand can be covered entirely. In the remaining period of the year only 1/3 to 2/3 of the monthly demand can be covered.

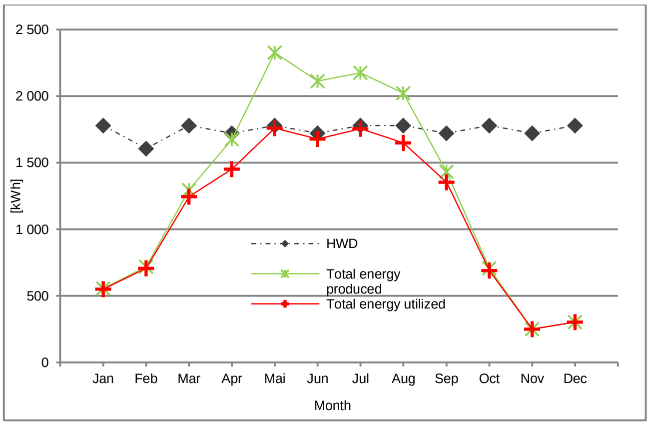

Figure 42 Case 2: Solar thermal output and the hot water demand

The output of the PV modules in Case 2 has increased by 44 per cent compared to Case 1 (Figure 43).

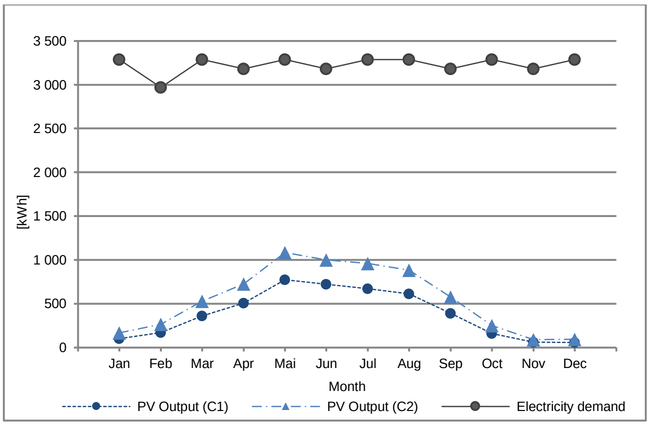

Figure 43 Case 2: Photovoltaic output and the electricity demand

Following graphs show the days of highest and lowest PV output for the Case 2. On day 167 ca. 53 per cent of electricity demand can be covered by the PV panels, and on day 356 only 6.9 per cent can be generated from the PV system.

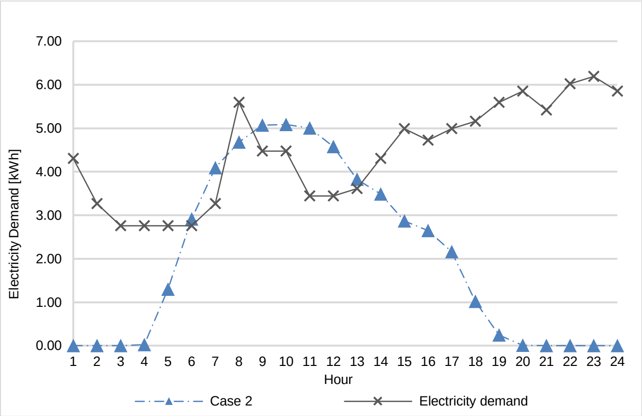

Figure 44 Daily profile of electricity demand in comparison to the highest PV output on day 167 for Case 2

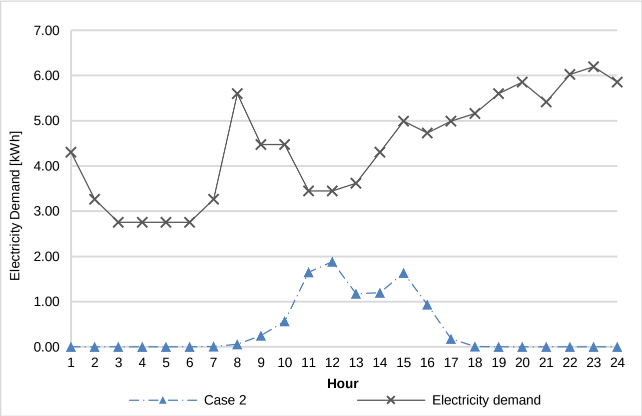

Figure 45 Daily profile of electricity demand in comparison to the lowest PV output on day 356 for Case 2

Figure 46 shows the PV output subdivided and categorized by the amount of kWh and the number of days reaching this amount. In this case 35 per cent of the year the output is less than 10 kWh. Compared to Case 1 there is a clear increase in days providing more than 30 kWh, which comes to almost 30 per cent. Remembering in Case 1 only 11 per cent of the year is the most productive.

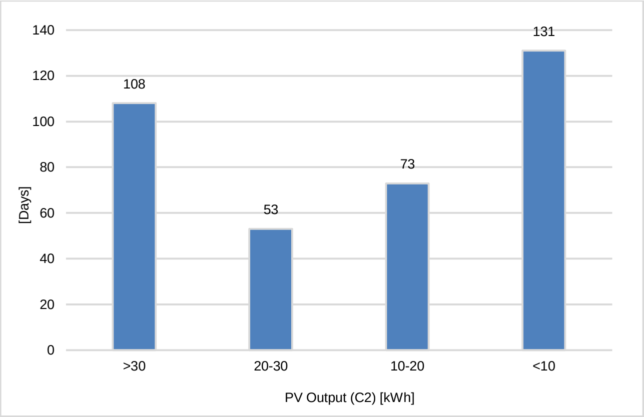

Figure 46 *Number of days of the annual PV output categorized by the amount of its output for Case 2*

4.4 Life Cycle Cost Assessment

As already mentioned in the methodology chapter, seven different variants were calculated and mutually compared. Table 22 shows how each calculated variant is structured. There are three set of options. Each option includes few variant types. Full description of the variant options can be read from chapter 3.6.2.

Table 23 shows each category and its costs in Euro. The first three variants have no investments of CG300 – Building construction, because these are the Scenario 1 whit no refurbishment measures. The investment costs for variant 4 and 5 – Austrian standard – are less than for 6 and 7 which represents the Passive House standard with obviously higher investment costs in the construction refurbishment. The investment cost for CG400 raise gradually with every variant, due to larger technical systems. Total investment represents the sum of the previous two categories. The following categories are the ongoing annual costs for the building. These are the costs for heating coming from the district supplier, the power costs as well the maintenance costs of all facilities. Additional to all costs, the savings from the solar thermal as well as the photovoltaic system are listed. Finally the Annual energy costs represent all annual spending for heating and power after savings.

Table 24 Life Cycle Cost categories and costs for all seven variants in Euro

Category	Variant						
	1	2	3	4	5	6	7
Cost Group 300	-	-	-	38,728	38,728	86,410	86,410
Cost Group 400	41,200	94,400	95,860	77,500	78,900	72,300	73,700
Total Investment	41,200	94,400	95,800	116,228	117,628	158,710	160,110
District Heating Costs	7,484	6,144	6,369	2,601	2,826	1,104	1,329
Power Costs	1,922	1,922	1,922	1,922	1,922	1,922	1,922
Maintenance Costs	453	1,030	1,054	853	868	795	811
Solar Thermal Savings	-	1,339	1,114	1,339	1,114	1,339	1,114
PV Pay-back	-	872	1,259	872	1,259	872	1,259
Annual Energy Costs	9,406.23	7,195.06	7,032.42	3,652.18	3,489.53	2,155.32	1,992.67

Following figures show the results of the calculations of all seven variants which were presented in previous table.

Variant 1 has the lowest investments of all seven. This is due to the fact that only costs of a new heating system apply. For the next six variants the investment of the technical systems in the building are the same. The investments of CG300 for the variants 6 and 7 (Passive House standard) are more than double higher than the costs for variants 4 and 5 (Austrian standard) (Figure 47). This will have an enormous effect on the LCC result calculated over a 20 year period. Figure 48 shows proportions of the annual costs of individual cost group.

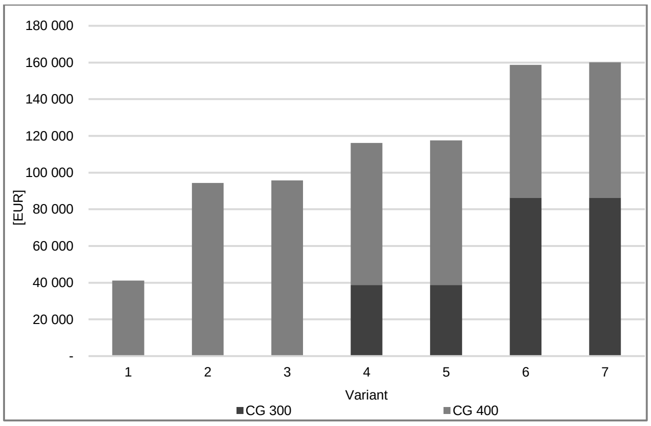

Figure 47 Total investments for the examined seven variants including the CG300 and CG400 in Euro

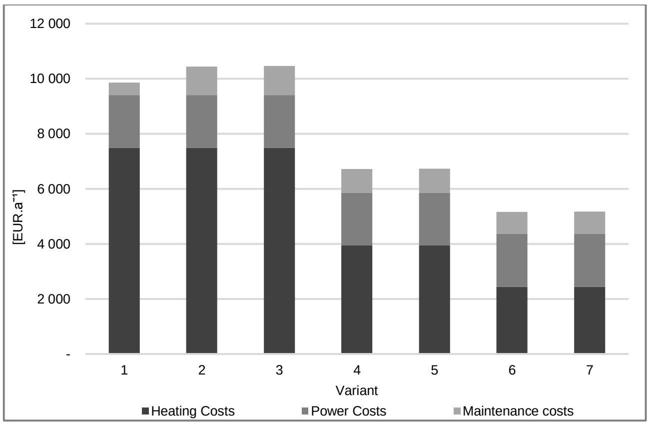

Figure 48 Proportions of the individual cost categories in the total life cycle costs before savings in Euro

Next two charts illustrate the thermal energy costs and savings made by the solar thermal system as well the power cost and the payback of the photovoltaic system. A distinct pattern is illustrated. While the variants 2 and 3 with no refurbishment action but applied solar systems show very small amount of saving in thermal energy costs, the variants with refurbishment measures can save from 1/3 (ca. 28-34%) to ½ (ca. 45-55%) of the thermal energy costs.

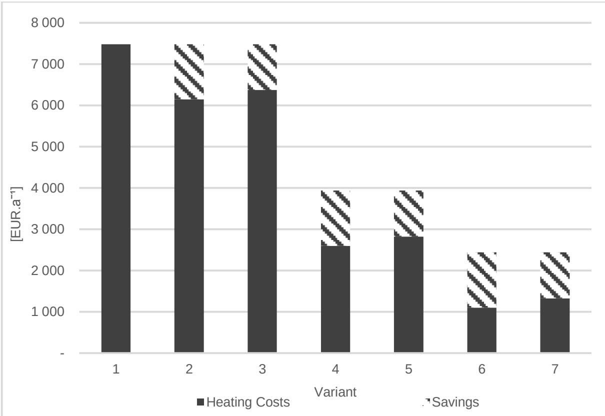

Figure 49 Annual heating costs and savings from the solar thermal output in Euro

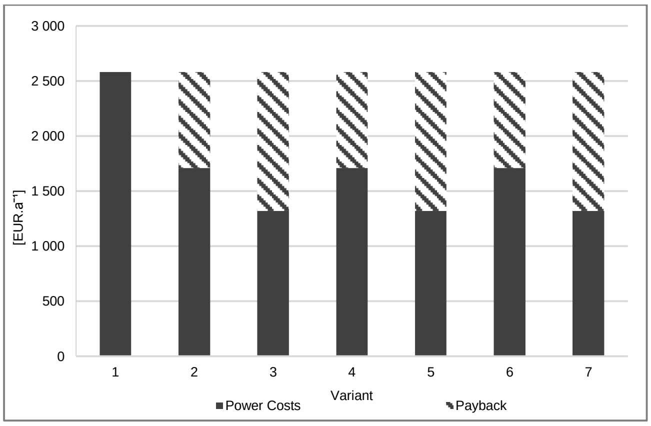

Figure 50 Annual power cost and payback from the PV output in Euro

4.5 Summary and Comparison

This chapter demonstrates a summary discussion with comparison of the results. It is divided in three sections: thermal quality of the study case building, the solar systems performance and the economic efficiency of these systems.

4.5.1 Simulated Energy Demand

As mentioned in the earlier chapter (see chapter 3.4) three different scenarios were selected to illustrate the thermal improvement possibilities of the building. The first scenario (S1) represents the existing condition of the building and the total energy demand amounts to 102,441 kWh.a^{-1} for heating and hot water. The second scenario (S2) involves improvement of the thermal building envelope according to Austrian standards which shows distinct decrease in heating demand and thereby in TED – 37,509 kWh.a^{-1}. The third scenario (S3) involves improvements of the building's thermal envelope according to Passive House standard and the TED amounts to 27,600 kWh.a^{-1}. Table 25 summarizes simulated space heating demand as well as the hot water demand for the above mentioned scenarios. Figure 51 shows the proportions of the hot water and heating demand referring to the total thermal energy demand. In Scenario 1 almost 80 per cent of the total thermal energy demand accounts for the heating energy. In Scenario 2 the heating and hot water demand almost balance. Scenario 3 can reduce the heating demand to 24 per cent relating to the total thermal energy demand.

Table 25 Summary of annual values of heating and domestic hot water energy demand in kWh.a^{-1}

Scenario	Heating Demand	Hot Water Demand	TED (HD+HWD)
	kWh.a^{-1}		
S1	81,502	20,939	102,441
S2	16,570	20,939	37,509
S3	6,661	20,939	27,600

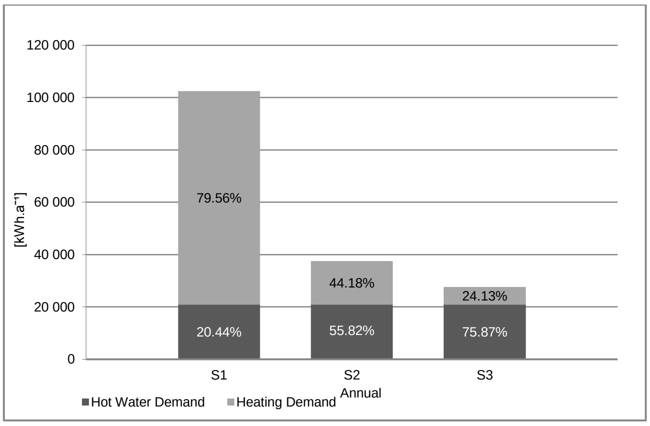

Figure 51 Annual hot water and heating demand for all three scenarios

4.5.2 Solar Systems Performance

This section shows the summarized results of the solar systems simulation outputs. In the following graphs the portion of covered and not covered energy demand are presented. Figure 52 and Figure 53 show the covered and not covered thermal energy demand for Case 1 and Case 2. The simulated outputs for S1 show a coverage of about 16,875 $kWh.a^{-1}$ of the total thermal energy demand. Scenario 2 and 3 show a slightly decrease in portion covered energy due to the better thermal performance of the building. Case 1 represents the bigger solar panel size and therefore show a certain amount of surplus energy, in fact lost energy. The better the thermal performance of the building, the more surplus energy solar thermal system is producing (Figure 52). Figure 53 shows the solar coverage for the C2 which covers only the hot water demand. Around 61 per cent of the total hot water demand can be covered by the solar thermal output of C2.

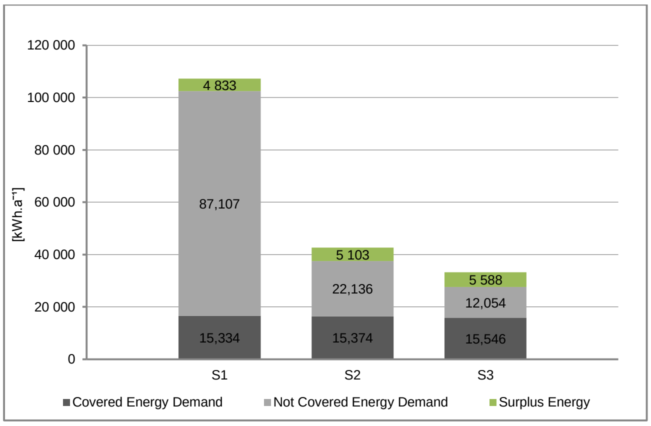

Figure 52 Comparison between scenarios of the solar thermal output of Case 1 and the non-renewable energy needed to meet the TED of the building in kWh.a^{-1}

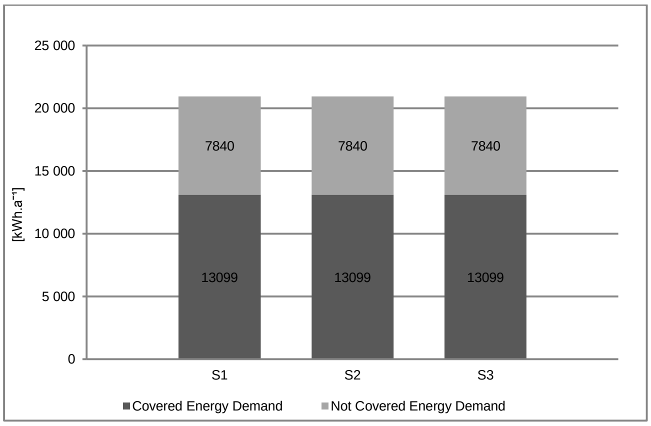

Figure 53 Presented solar thermal output of Case 2 and the non-renewable energy required to meet the HWD of the building in kWh.a^{-1}

The photovoltaic system calculations imply rather low output of the selected building. Both cases (C1 and C2). Case 1 can cover only ca. 11 per cent and Case 2 ca. 17 per cent of the total annual electricity demand (Figure 54). However, this output results seem not to confirm the initial intentions. This is in addition to the fact that the PV modules were placed on the north-east side and this therefore not optimally orientated. The addition of PV modules on the south-west roof side as a complementary solution couldn't change the overall result to be satisfactory (Figure 55). In further analysis a life cycle cost assessment will bring more details how cost efficient this solar systems are in this specific study case. Figure 56 shows the percentage of photovoltaic coverage for both cases monthly over a calculated year.

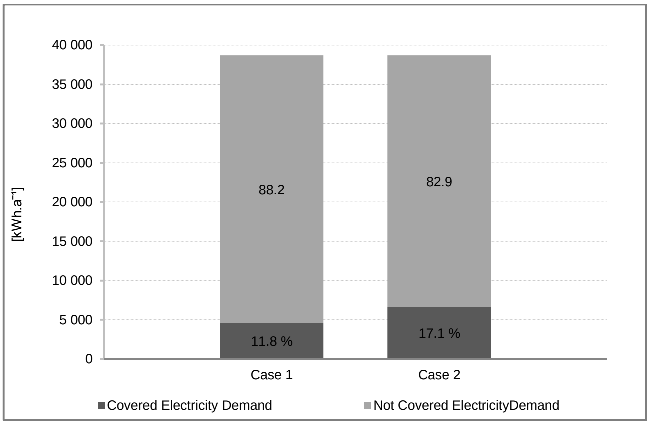

Figure 54 Photovoltaic output of Case 1 and Case 2 compared with the total electricity demand

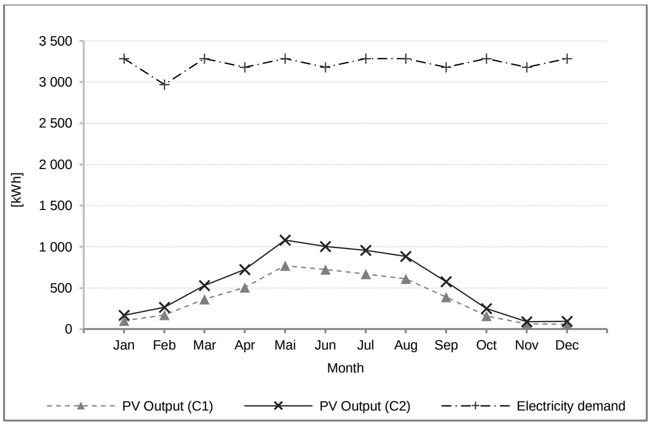

Figure 55 Solar coverage of Case 1 and Case 2 for the electricity demand and photovoltaic output

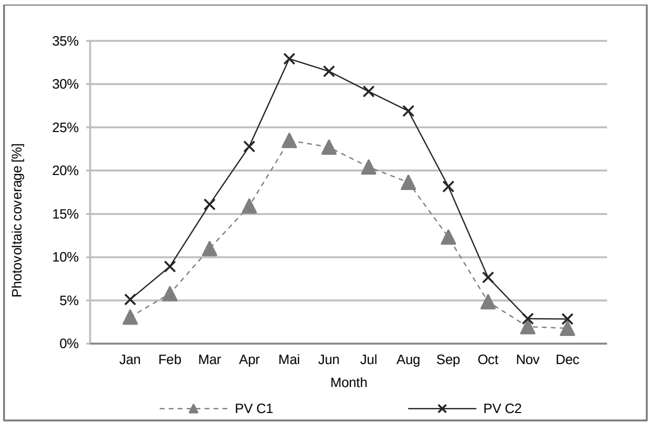

Figure 56 Solar coverage of C1 and C2 for the electricity demand and photovoltaic output

4.5.3 Life Cycle Cost Assessment

This section contains an assessment of the economic efficiency of the applied solar systems. The calculated options show a distinct outcome. Considering the amortization period of 20 years variants 4 and 5 happen to be the most cost effective solution in this specific study case (Figure 57).

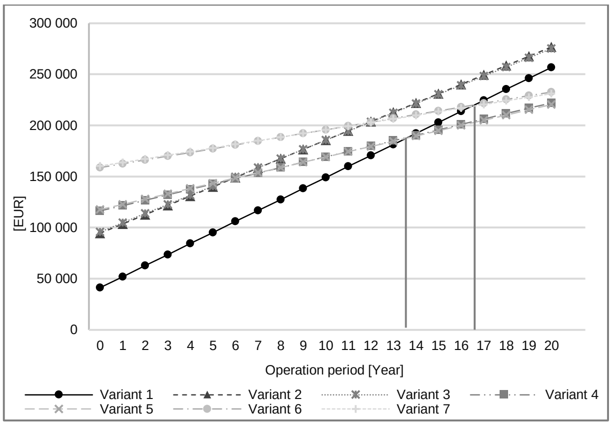

Figure 57 Cumulated costs of the seven variants over the 20 year operation period

Variant 1 starts at 41,200 EUR investment costs and reaches after 20 year operation costs of ca. 256,081 EUR. Without any refurbishment measures and only application of solar systems (Variants 2 and 3) the amortisation may be reached after 31 years of operation. Considering that the solar systems have limited duration period, this option is not profitable and applicable. The warranty conditions for PV panels typically guarantee that panels can still produce at least 80 per cent of their initial rated peak output after 20 (sometimes 25) years. So manufactures expect that their panels last at least 20 years, and that the efficiency decreases by no more than 1 per cent per year (CAT 2014). In order to reach most cost-effective option, several structural measures need to be taken. Following variants show the amortisation over the operation period with structural measures taken for two steps of refurbishment, the Austrian standard and Passive House standard. The variants with the first step of refurbishment (Austrian standard) starts with ca. 116,227-117,627 EUR investment costs and reach the pay-back time after ca. 14 years of operation. The sixth and seventh variant (Passive House standard) have ca. 158,709-160,109 EUR investment cost and amortise after ca. 17 years. The reason for the later amortisation with the refurbishment by Passive House standard is that it has enormous investment costs at the start.

5 CONCLUSION AND FUTURE RESEARCH

The aim of this study was to examine the energy supply by means of dynamic system simulations of a proposed existing multifamily dwelling with 10 residential units. For this purpose three scenarios in terms of thermal performance were simulated. Furthermore solar systems were applied in order to cover building's energy demand. Finally, a cost estimation was performed to see how cost effective these solutions are.

The simulations demonstrate that improvement of the building envelope showed – as expected – a distinct lower heating demand compared to the current state. Savings from 79 to 91 per cent can be achieved if just the building thermal envelope is improved according to the Austrian standards or Passive House standards. The solar thermal system of 80m² collector area produces about 21,459 $kWh.a^{-1}$ of thermal energy. 15,584 $kWh.a^{-1}$ can be used for the hot water demand. The remaining 5,875 $kWh.a^{-1}$ energy (before system losses) could theoretically cover a good fraction of the heating demand of a Passive House Standard building. But the main problem here represents how to store this surplus energy gained in summer for the winter period when it's actually needed. In the area of the existing buildings rarely optimal conditions for the subsequent use of solar thermal systems is given and designers and installers are facing various difficulties in implementation. The implementation of large buffer storages depends on the local prerequisites like geological a hydro-geological situation of the site. With a simulated photovoltaic system the annual amount of electricity was calculated. This resulted in 11 to 17 per cent of the annual power demand. Ultimately, a great coverage of the hot water demand and modest energy exports of photovoltaic power are still possible.

In order to make a definite conclusion whether the applied solar systems are cost effective or not, a life cycle cost assessment was performed. This showed that refurbishment to the Austrian standard is most cost effective solution. The constructional investments for the Passive House standard scenario are distinctive higher than in the Austrian standard scenario. The amortization period occurs between 14 to 17 years. In this study the Passive House standard case revealed a longer payback period due to the enormous investment costs at the beginning.

The implemented dynamic simulation model in this research gives a more comprehensive understanding of the performance of the solar thermal and photovoltaic systems. Furthermore, it allows the possibility to compare, evaluate and optimize. Future efforts can involve simulations on a larger scale with detailed building systems modelling. From the technical point of view it can be stated that the used simulation software sets certain limitations in modelling geometrical complex buildings. Moreover access to additional software tools could contribute to exact planning of the HVAC and solar systems in order to gain more accurate results.

In the technical and architectural integration of such systems, however, designers and installers are often faced with major problems. The construction of local solar heating systems for the existing building stock is a further important keystone in increasing the use of solar energy.

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6.2 List of Figures

6.3 List of Tables

7 APPENDIX

7.1 Submission plan

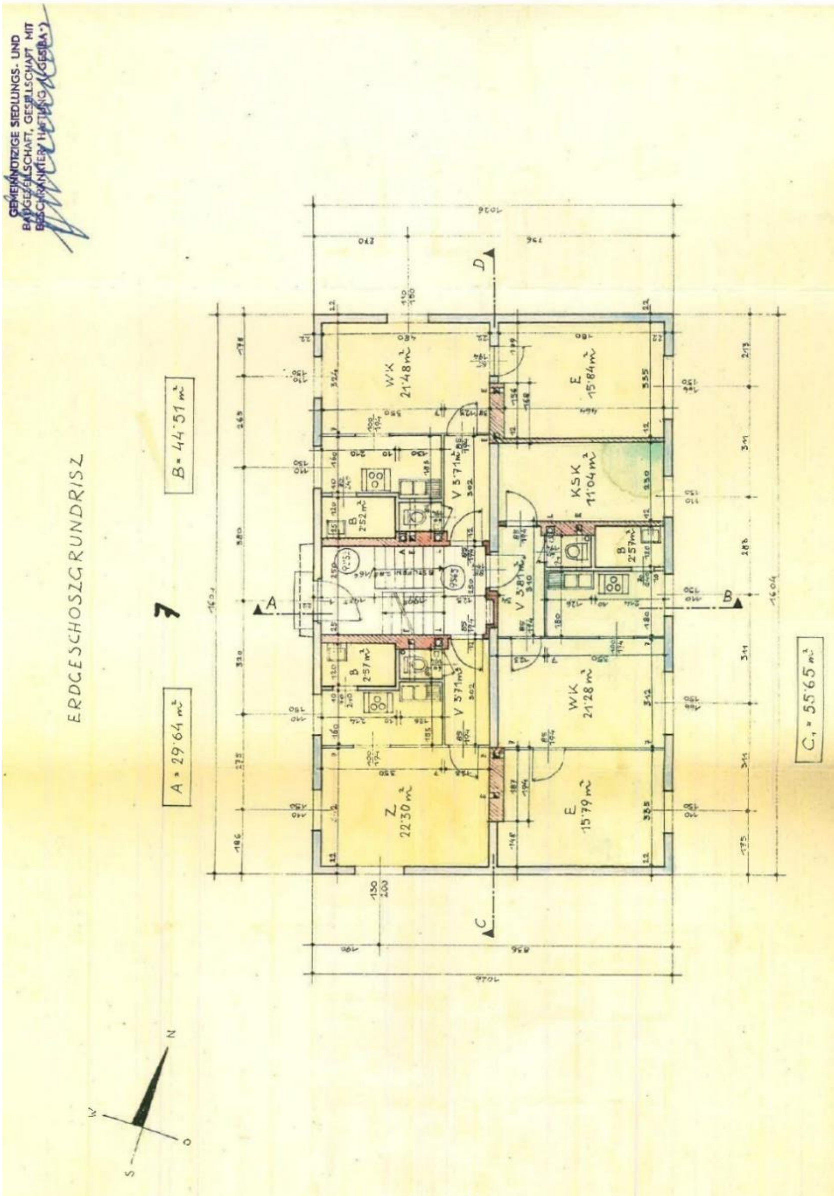
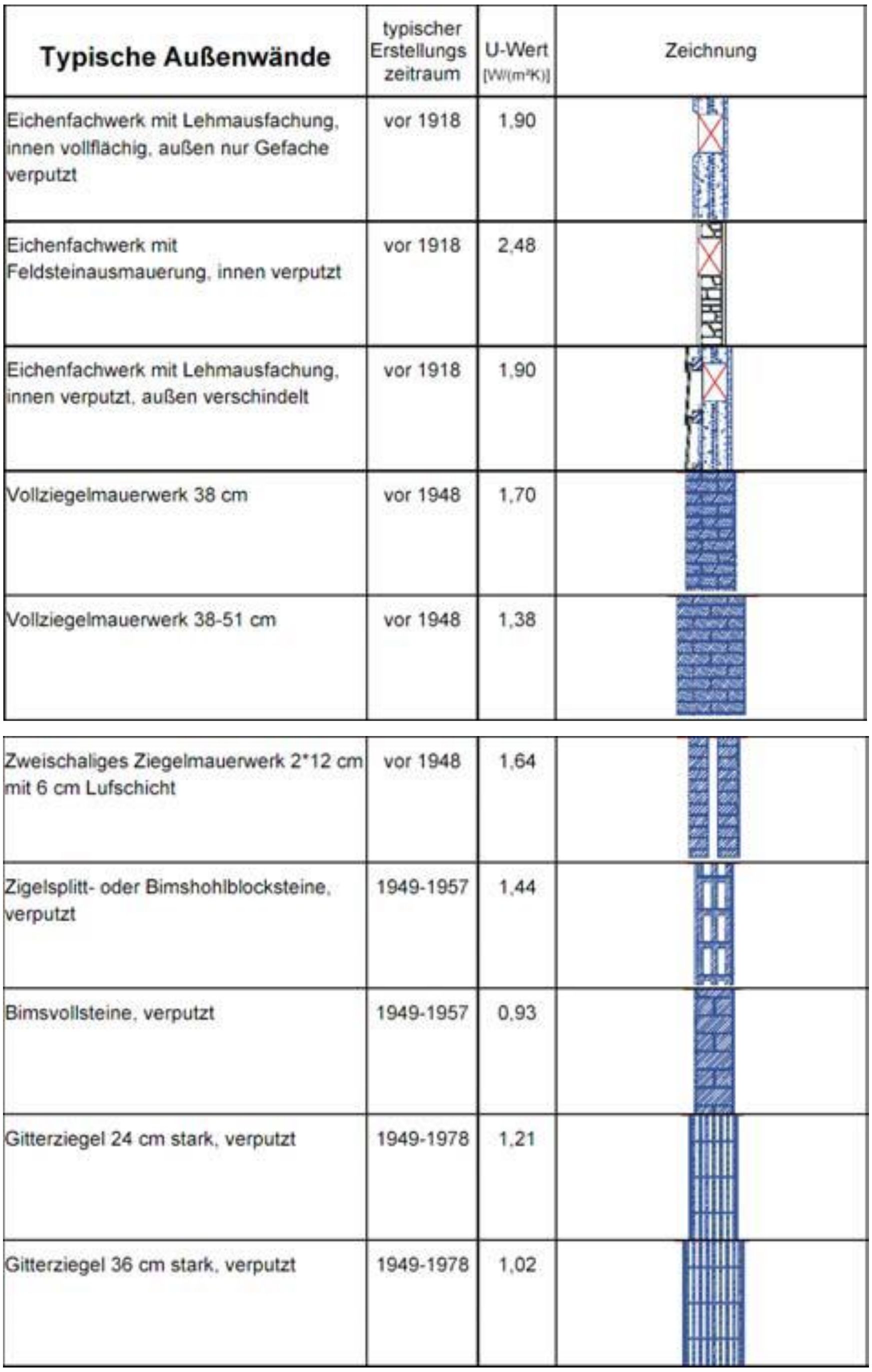


Figure A 1 Original existing plan used as basis for the 3D modelling (source: TU Vienna)

7.2 Optimus construction compilation



Typische Außenwände	typischer Erstellungs zeitraum	U-Wert [W/(m²K)]	Zeichnung
Eichenfachwerk mit Lehmausfachung, innen vollflächig, außen nur Gefache verputzt	vor 1918	1,90	
Eichenfachwerk mit Feldsteinausmauerung, innen verputzt	vor 1918	2,48	
Eichenfachwerk mit Lehmausfachung, innen verputzt, außen verschindelt	vor 1918	1,90	
Vollziegelmauerwerk 38 cm	vor 1948	1,70	
Vollziegelmauerwerk 38-51 cm	vor 1948	1,38	
Zweischaliges Ziegelmauerwerk 2*12 cm mit 6 cm Lufschicht	vor 1948	1,64	
Zigelsplitt- oder Bimshohlblocksteine, verputzt	1949-1957	1,44	
Bimsvollsteine, verputzt	1949-1957	0,93	
Gitterziegel 24 cm stark, verputzt	1949-1978	1,21	
Gitterziegel 36 cm stark, verputzt	1949-1978	1,02	

Figure A 2 Typical external wall constructions of the period from 1918 to 1978 (source: Optimus)

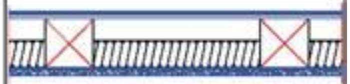
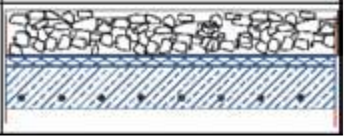
Typische Geschossdecken und Flachdächer	typischer Erstellungs zeitraum	U-Wert $[W/(m^2K)]$	Zeichnung
Holzbalkendecke mit Strohlehmwickel, oberseitig Dielung (Eiche oder Fichte), unterseitig verputzt	bis 1918	1,04	
Holzbalkendecke mit Blindboden und Lehmschlag, 2-3 cm Schlackenschüttung, oberseitig Dielung, unterseitig Putz auf Spalierlatten	bis 1918	0,78	
Holzbalkendecke mit Strohlehmwickel, oberseitig Dielung (Eiche oder Fichte), unterseitig Putz auf Spalierlatten	bis 1918	1,03	
Holzbalkendecke mit Blindboden, oberseitig Dielung, unterseitig Putz auf Spalierlatten	bis 1918	0,78	
Stahlsteindecke mit Gußasphaltestrich	1949-1957	2,08	
Stahlbetondecke 15 cm ohne Dämmung	1958-1968	2,25	
Stahlsteindecke mit 1 cm Dämmung, schwimmender Estrich	1958-1968	1,37	
Stahlbetonflachdach 20cm mit 16cm Luftschicht	1958-1968	1,68	
Flachdach, 15 cm Stahlbetondecke + 2 cm WD + Dachhaut	1969-1978	1,23	
Flachdach, 15 cm Stahlbetondecke + 6 cm Schaumglas + Dachhaut + Kiesschüttung	1969-1978	0,63	

Figure A 3 Typical floors and flat roof constructions of the period from 1918 to 1978 (source: Optimus)

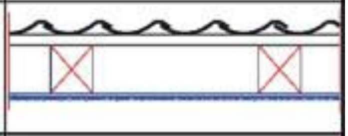
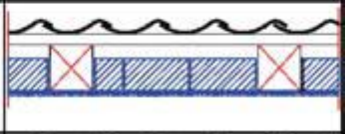
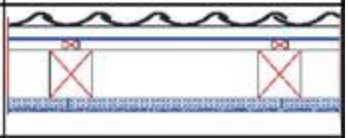
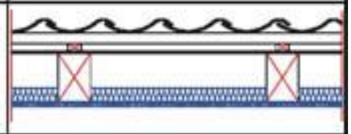
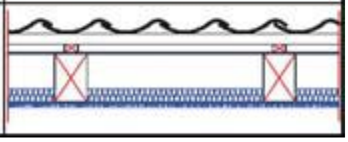
Typische Steildächer	typischer Erstellungs zeitraum	U-Wert [W/(m²K)]	Zeichnung
Putz auf Spalierlatten	bis 1948	3,08	
Bimsvollsteine zwischen den Sparren, verputzt	1949-1957	1,41	
Heraklithplatten unter den Sparren, verputzt	1958-1978	1,11	
Steildach, 4 cm Dämmung zwischen den Sparren	1958-1968	0,79	
Steildach, 6 cm Dämmung zwischen den Sparren	1969-1978	0,51	

Figure A 4 Typical steep roof constructions of the period until 1978

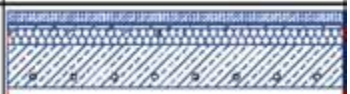
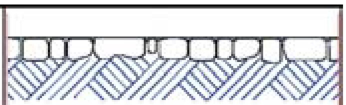
Typische Kellerdecken und EG-Fußböden	typischer Erstellungs zeitraum	U-Wert [W/(m²K)]	Zeichnung
Holzbalkendecke mit Strohlehmwickel, unterseitig verputzt	bis 1918	1,04	
Holzbalkendecke auf Blindboden mit Lehmschlag, oberseitig Dielung	bis 1918	0,91	
gemauertes Kappengewölbe, oberseitig Sandschüttung, Dielung auf Lagerhölzern	bis 1918	1,37	
scheitrechte Kappendecke, oberseitig Sandschüttung, Dielung auf Lagerhölzern	1918-1948	1,11	
12 cm Stahlbetondecke, oberseitig 6-8 cm Schlackenschüttung + Dielung auf Lagerhölzern	1949-1957	1,01	
Stahlbetondecke mit Estrich	1949-1957	2,40	
12-16 cm Stahlbetondecke, 2-3 cm Trittschaldämmung aus Polystyrol, 4 cm Estrich	1958-1978	0,84	
Stahlsteindecke mit Gußasphaltestrich	1958-1978	2,08	
Feldsteine, in Sand (nicht unterkellert)	bis 1918	2,88	

Figure A 5 Typical basement ceilings and ground floor constructions of the period from 1918 to 1978

7.3 Construction components

Table A 1 Construction compilation for Scenario 1

Construction	Material	TAS material	Width (m)	Width (mm)	Conductivity (W/mK)	Spec.heat (J/kgC)	Density (kg/m³)	Vapour Diffusion Factor	Solar Reflectance		Emissivity		d/λ	U-value [W/m²K]
									Ext.	Int.	Ext.	Int.		
External wall - basement	Plaster inside	am1plast\16	0.01	10	0.72	837	1680	11	0.6	0.6	0.9	0.9	0.014	0.95
	Foamed SLAG concrete block	am1block\3	0.25	250	0.6	1050	2000	34	0.35	0.35	0.9	0.9	0.417	
	Wood Wool Slab	am1ins\20	0.03	30	0.067	1000	300	2.88	0.4	0.4	0.9	0.9	0.448	
External wall	Plaster inside	am1plast\16	0.01	10	0.72	837	1680	11	0.6	0.6	0.9	0.9	0.014	1.73
	Foamed SLAG concrete block	am1block\3	0.22	220	0.6	1050	2000	5	0.35	0.35	0.9	0.9	0.367	
	Plaster outside	am1plast\16	0.02	20	0.72	837	1680	11	0.6	0.6	0.9	0.9	0.028	
Soil adjacent floor / basement floor	Concrete screed	am1concd\9	0.04	40	1.28	1000	2100	34	0.35	0.35	0.9	0.9	0.031	1.71
	Concrete	am1concd\4	0.1	100	1.83	920	2400	24	0.35	0.35	0.9	0.9	0.055	
	Earth coarse gravelly	am1soil\3	0.15	150	0.52	1824	2050	999	0.18	0.18	0.91	0.91	0.288	
	Soil													
Floor (between basement and ground floor)	Planked floor	am1wood\15	0.01	10	0.22	1420	610	11.42	0.4	0.4	0.9	0.9	0.045	0.86
	Woodwool Slab	am1ins\23	0.03	30	0.13	1000	800	5.2	0.4	0.4	0.9	0.9	0.231	
	Slag fill	am1aggr\33	0.08	80	0.59	1056	1790	14.8	0.35	0.35	0.9	0.9	0.136	
	Pumice concrete block	am1block\6	0.12	120	0.3	1110	2400	100	0.35	0.35	0.9	0.9	0.400	
	Plaster	am1plast\16	0.01	10	0.72	837	1680	11	0.6	0.6	0.9	0.9	0.014	
Upmost ceiling (to cold roof space)	Slag fill	am1aggr\33	0.06	60	0.59	1056	1790	14.8	0.35	0.35	0.9	0.9	0.102	1.17
	Pumice concrete block	am1block\6	0.12	120	0.3	1110	2400	100	0.35	0.35	0.9	0.9	0.400	
	Plaster	am1plast\16	0.01	10	0.72	837	1680	11	0.6	0.6	0.9	0.9	0.014	
Roof	Roofing felt	am1asph\9	0.005	5	0.41	1000	960	1300	0.26	0.26	0.91	0.91	0.012	1.45
	20mm air (upward flow)	am1cav\12	0.02	20	0.12	0	0	1					0.169	
	Pumice concrete block	am1block\6	0.08	80	0.3	1110	2400	100	0.35	0.35	0.9	0.9	0.267	
	Roof tile with slat	www.u-wert.net	0.075	75	0.75	840	933.3	14	0.5	0.5	0.9	0.9	0.100	
Window	Window glas	optclear\1 (opt\10)	0.004	4	1	0	0	99999	0.07	0.07				1.453
	12mm Argon	am1cav\28	0.012	16		0	0	1	0	0				
	Window glas	optclear\1 (opt\10)	0.004	4	1	0	0	99999	0.07	0.07				
Door														4.762

Table A 2 Construction compilation for Scenario 2

Construction	Material	TAS material	Width (m)	Width (mm)	Conductivity (W/mK)	Spec.heat (J/kgC)	Density (kg/m³)	Vapour Diffusion Factor	Solar Reflectance		Emissivity		d/λ	U-value
									Ext.	Int.	Ext.	Int.		
External wall - basement	Plaster inside	am1plast\16	0.01	10	0.72	837	1680	11	0.6	0.6	0.9	0.9	0.014	0.35
	Foamed SLAG concrete block	am1block\1	0.25	250	0.317	1050	1040	14.8	0.3	0.3	0.9	0.9	0.789	
	Polyurethane, foamed	am1ins\16	0.05	50	0.026	1260	30	60	0.4	0.4	0.9	0.9	1.923	
External wall	Plaster inside	am1plast\16	0.01	10	0.72	837	1680	11	0.6	0.6	0.9	0.9	0.014	0.33
	Foamed SLAG concrete block	am1block\1	0.22	220	0.319	880	750	5	0.3	0.3	0.93	0.93	0.690	
	Expanded Polystirene	am1ins\15	0.08	80	0.038	1380	140	59	0.6	0.6	0.9	0.9	2.105	
	Plaster outside	am1plast\16	0.02	20	0.72	837	1680	11	0.6	0.6	0.9	0.9	0.028	
Soil adjacent floor / basement floor	Concrete screed	am1concd\9	0.04	40	1.28	1000	2100	34	0.35	0.35	0.9	0.9	0.031	0.34
	Polyurethan board	am1ins\17	0.06	60	0.025	1400	30	98	0.4	0.4	0.9	0.9	2.400	
	Concrete screed	am1concd\9	0.04	40	1.28	1000	2100	34	0.35	0.35	0.9	0.9	0.031	
	Concrete	am1concd\4	0.1	100	1.83	920	2400	24	0.35	0.35	0.9	0.9	0.055	
	Earth coarse gravelly	am1soil\3	0.15	150	0.52	1824	2050	999	0.18	0.18	0.91	0.91	0.288	
	Soil					1480								
Floor (between basement and ground floor)	Planked floor	am1wood\15	0.01	10	0.22	1420	610	11.42	0.4	0.4	0.9	0.9	0.045	0.37
	Glass fibre	am1ins\2	0.03	30	0.035	1000	25	2.88	0.4	0.4	0.9	0.9		
	Concrete screed	am1concd\9	0.03	30	1.28	1000	2100	34	0.35	0.35	0.9	0.9	0.023	
	Pumice concrete block	am1block\6	0.12	120	0.3	1110	2400	100	0.35	0.35	0.9	0.9	0.400	
	Expanded polystyrene	am1ins\15	0.06	60	0.03	1380	140	59	0.6	0.6	0.9	0.9	2.000	
	Plaster	am1plast\16	0.01	10	0.72	837	1680	11	0.6	0.6	0.9	0.9	0.014	
Upmost ceiling (to cold roof space)	Planked floor	am1wood\15	0.01	10	0.22	1420	610	11.42	0.4	0.4	0.9	0.9	0.045	0.38
	Glass fibre	am1ins\2	0.07	70	0.035	1000	25	2.88	0.4	0.4	0.9	0.9	2.000	
	Concrete screed	am1concd\9	0.03	30	1.28	1000	2100	34	0.35	0.35	0.9	0.9	0.023	
	Pumice concrete block	am1block\6	0.12	120	0.3	1110	2400	100	0.35	0.35	0.9	0.9	0.400	
	Plaster	am1plast\16	0.01	10	0.72	837	1680	11	0.6	0.6	0.9	0.9	0.014	
Roof	Roofing felt	am1asph\9	0.005	5	0.41	1000	960	1300	0.26	0.26	0.91	0.91	0.012	0.18
	20mm air (upward flow)	am1cav\12	0.02	20	0.12	0	0	1					0.169	
	Glass fibre	am1ins\2	0.15	150	0.03	1000	25	2.88	0.4	0.4	0.9	0.9	5.000	
	Roof tile with slat	www.u-wert.net	0.075	75	0.75	840	933.3	14	0.5	0.5	0.9	0.9	0.100	
Window	6mm glass	kglass\1	0.006	8		0	0	99999	0.1	0.1				1.36
	12mm Argon	am1cav\28	0.012	16		0	0	1	0	0				
	6mm optifloat clear	optclear\2	0.006	6		0	0	99999	0.07	0.07				
Door														1.70

Table A 3 Construction compilation for Scenario 3

Construction	Material	TAS material	Width (m)	Width (mm)	Conductivity (W/mC)	Spec.heat (J/kgC)	Density (kg/m³)	Vapour Diffusion Factor	Solar Reflectance		Emissivity		d/λ	U-value
									Ext.	**Int.**	**Ext.**	**Int.**		
External wall - basement	Plaster inside	am1plast\16	0.01	10	0.72	837	1680	0.6	0.6	0.9	0.9	0.014	0.014	0.12
	Foamed SLAG Conc. partition block	am1block\1	0.25	250	0.317	1050	1040	0.3	0.3	0.9	0.9	0.789	0.789	
	POLYURETHANE, foamed	am1ins\16	0.2	200	0.026	1260	30	0.4	0.4	0.9	0.9	7.692	7.692	
External wall	Plaster inside	am1plast\16	0.01	10	0.72	837	1680	0.6	0.6	0.9	0.9	0.014	0.014	0.13
	Foamed SLAG Conc. partition block	am1block\1	0.22	220	0.319	880	750	0.3	0.3	0.93	0.93	0.690	0.690	
	Expanded Polystirene	am1ins\15	0.25	250	0.038	1380	140	0.6	0.6	0.9	0.9	6.579	6.579	
	Expanded polystyrene	am1plast\16	0.02	20	0.72	837	1680	0.6	0.6	0.9	0.9	0.028	0.028	
Soil adjacent floor / basement floor	Concrete screed	am1concd\9	0.04	40	1.28	1000	2100	0.35	0.35	0.9	0.9	0.031	0.031	0.12
	Polyurethan board	am1ins\17	0.2	200	0.025	1400	30	0.4	0.4	0.9	0.9	8.000	8.000	
	Concrete screed	am1concd\9	0.04	40	1.28	1000	2100	0.35	0.35	0.9	0.9	0.031	0.031	
	Concrete	am1concd\4	0.1	100	1.83	920	2400	0.35	0.35	0.9	0.9	0.055	0.055	
	Earth coarse gravelly	am1soil\3	0.15	150	0.52	1824	2050	0.18	0.18	0.91	0.91	0.288	0.288	
Floor (between basement and ground floor)	Planked floor	am1wood\15	0.01	10	0.22	1420	610	0.4	0.4	0.9	0.9	0.045	0.045	0.12
	Glass fibre	am1ins\2	0.12	120	0.03	1000	25	0.4	0.4	0.9	0.9		4.000	
	Concrete screed	am1concd\9	0.03	30	1.28	1000	2100	0.35	0.35	0.9	0.9	0.023	0.023	
	Pumice concrete block	am1block\6	0.12	120	0.3	1110	2400	0.35	0.35	0.9	0.9	0.400	0.400	
	Expanded polystyrene	am1ins\15	0.12	120	0.03	1380	140	0.6	0.6	0.9	0.9	4.000	4.000	
	Plaster	am1plast\16	0.01	10	0.72	837	1680	0.6	0.6	0.9	0.9	0.014	0.014	
Upmost ceiling (to cold roof space)	Glass fibre	am1ins\2	0.28	280	0.035	1000	25	0.4	0.4	0.9	0.9	8.000	8.000	0.12
	Concrete screed	am1concd\9	0.03	30	1.28	1000	2100	0.35	0.35	0.9	0.9	0.023	0.023	
	Pumice concrete block	am1block\6	0.12	120	0.3	1110	2400	0.35	0.35	0.9	0.9	0.400	0.400	
	Plaster	am1plast\16	0.01	10	0.72	837	1680	0.6	0.6	0.9	0.9	0.014	0.014	
			0											
Roof	Lightweight plaster	am1plast\1	0.01	10	0.079	837	400	11			0.9	0.900	0.127	0.11
	Glass fibre	am1ins\2	0.3	300	0.035	1000	25	0.4	0.4	0.9	0.9	8.571	8.571	
	Roofing felt	am1asph\9	0.005	5	0.41	1000	960	0.26	0.26	0.91	0.91	0.012	0.012	
	20mm air (upward flow)	am1cav\12	0.02	20	0.12	0	0	1					0.169	
	Roof tile with slat	www.u-wert.net	0.075	75	0.75	840	933.3	0.5	0.5	0.9	0.9	0.100	0.100	
Window	Window glass	kglass\1	0.01	10	0.1	0	0	99999	0.07	0.07	0.185	0.845		0.80
	Gas layer	am1cav\11	0.015	15	0	0	0	1	0	0	0	0		
	Window glass	kglass\1	0.01	10	0.1	0	0	99999	0.07	0.07	0.185	0.845		
	Gas layer	am1cav\11	0.015	15	0	0	0	1	0	0	0	0		
	Window glass	kglass\1	0.01	10	0.1	0	0	99999	0.07	0.07	0.185	0.845		
Door														0.80

7.4 Domestic hot water demand

Table A 4 Domestic hot water demand used as basis for the hot water consumption in the study case building (source: Eder et al. 1999)

Gebäudeart	Bestimmung	Warmwasserbedarf in l à 60°C/d + kWh						
		Einheit	min [l]	kWh	mittel [l]	kWh	hoch [l]	kWh
Einfamilienhaus	einfacher Standard	Person	30	1,67	40	2,23	50	2,78
	mittlerer Standard	Person	35	1,95	50	2,78	60	3,34
	gehobener Standard	Person	40	2,23	60	3,34	80	4,45
Mehrfamilienhaus	soz. Wohnbau	Person	20	1,11	30	1,67	40	2,23
	allgem. Wohnbau	Person	30	1,67	40	2,23	50	2,78
	gehob. Wohnbau	Person	40	2,23	50	2,78	70	3,90
Gewerbe-Küchen	mäßig belegt	Eßplatz	15	0,84	20	1,11	30	1,67
Imbißstuben	stark belegt	Eßplatz	20	1,11	30	1,67	40	2,23
Gaststätten	Belegung mäßig	Eßplatz	10	0,56	15	0,84	15	0,84
	Belegung mittel	Eßplatz	20	1,11	25	1,39	35	1,95
	Belegung stark	Eßplatz	25	1,39	30	1,67	45	2,5
Speiserestaurants	Essen einfach	Essen	8	0,45	10	0,56	15	0,84
	Essen bis 3 Gänge	Essen	12	0,67	15	0,84	20	1,11
	Essen >4 Gänge	Essen	20	1,11	25	1,39	30	1,67
Gasthöfe, Hotels,	einfach	Bett	30	1,67	40	2,23	50	2,78
Appartementhäuser	2. Klasse	Bett	40	2,23	50	2,78	70	3,90
	1. Klasse	Bett	60	3,34	80	4,45	100	5,57
	Luxus	Bett	80	4,45	100	5,57	150	8,35
Kinderheime,	einfacher Standard	Bett	40	2,23	50	2,78	60	3,34
Altersheime	einfacher Standard	Bett	30	1,67	40	2,23	50	2,78
Krankenhäuser	je nach med.tech,Einr.							
	einfach	Bett	50	2,78	60	3,34	80	4,45
	durchschnittlich	Bett	70	3,90	80	4,45	100	5,57
	umfangreich	Bett	100	5,57	120	6,68	150	8,35

7.5 Electricity consumption profile

Table A 5 Use-related power consumption per household, depending on the number of dwellings in residential buildings (Source: Statistik Austria 2011)

No. Of flats	Purpose of use	kWh/ household				kWh/ person			
		2004	2006	2008	2010	2004	2006	2008	2010
10-19	Heating	361	372	477	327	199	207	270	221
	Cooking	312	293	285	276	169	158	154	156
	Cooling/ freezing	499	469	441	436	278	270	263	263
	Large appliances	375	364	359	346	189	191	198	194
	Small appliances	153	161	151	145	82	90	88	86
	Entertainment electronics	362	352	347	322	203	203	210	196
	Standby	227	233	225	213	125	131	137	132
	Lighting	423	421	395	380	227	234	232	224
	Other load	426	424	400	412	285	273	270	280
	Diffuse load	214	210	214	198	120	119	125	122
	Total	**3352**	**3299**	**3294**	**3055**	**1877**	**1876**	**1947**	**1874**

7.6 Solar Thermal Output

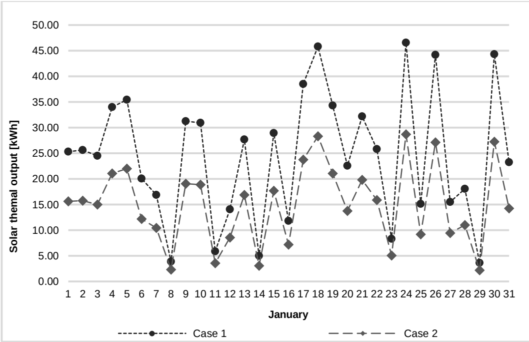


Figure A 6 Solar thermal output for January

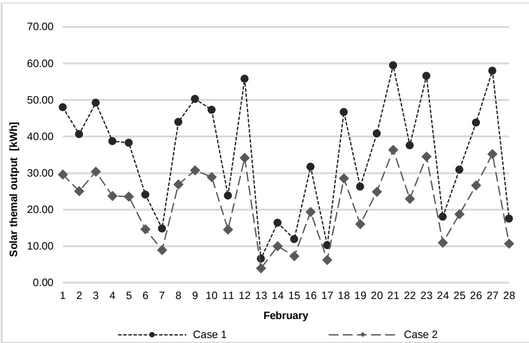


Figure A 7 Solar thermal output for February

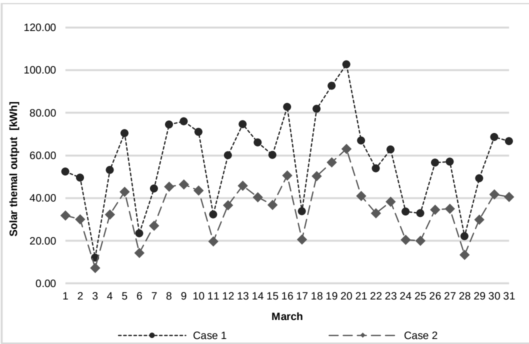


Figure A 8 Solar thermal output for March

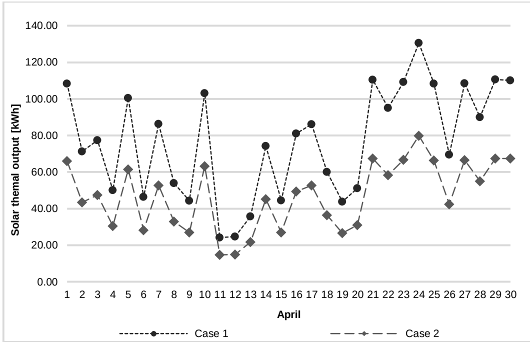


Figure A 9 Solar thermal output for April

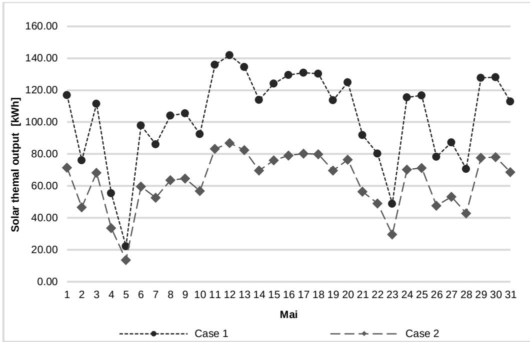


Figure A 10 Solar thermal output for Mai

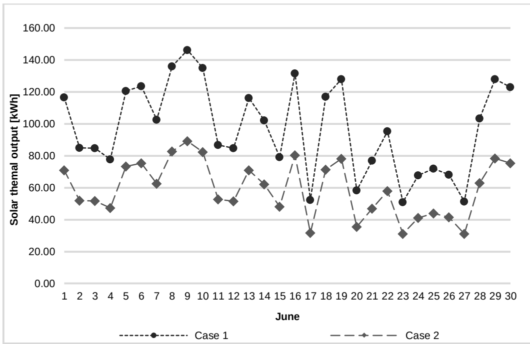


Figure A 11 Solar thermal output for June

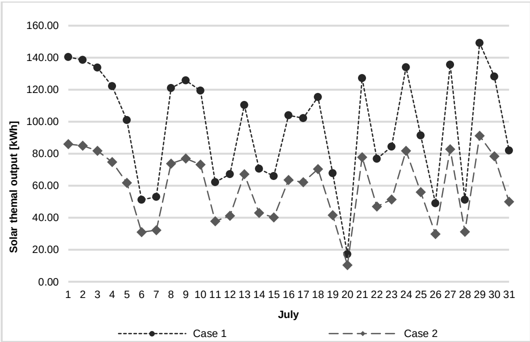


Figure A 12 Solar thermal output for July

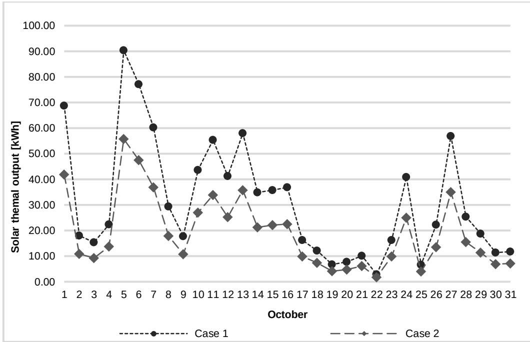


Figure A 15 Solar thermal output for October

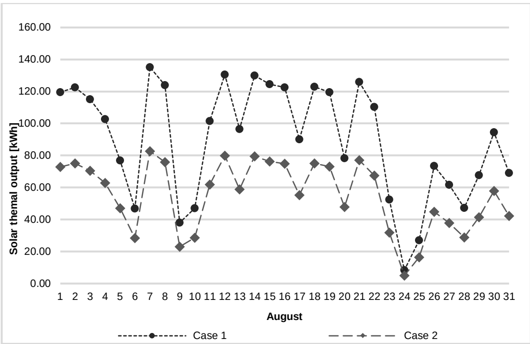


Figure A 13 Solar thermal output for August

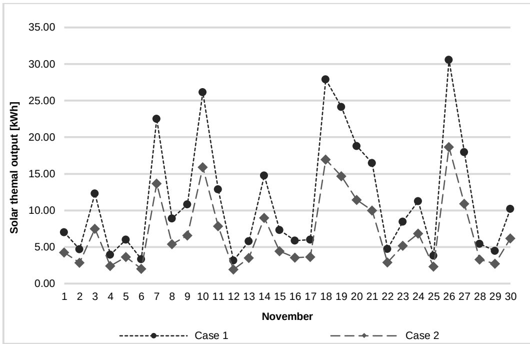


Figure A 16 Solar thermal output for November

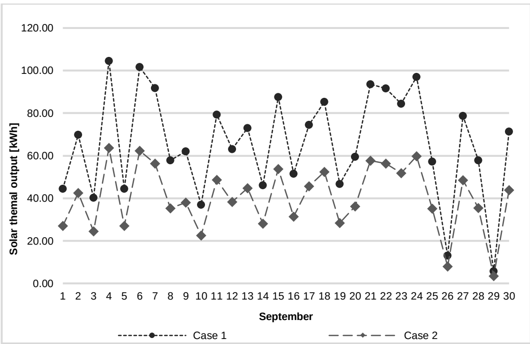


Figure A 14 Solar thermal output for September

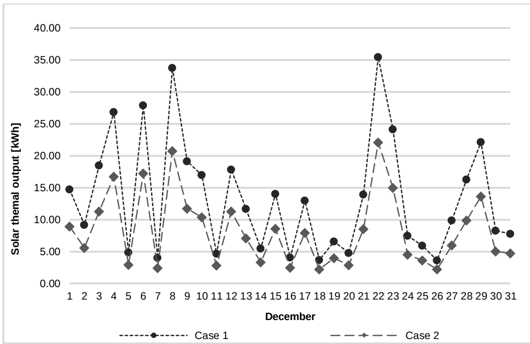


Figure A 17 Solar thermal output for December

7.7 PV Output

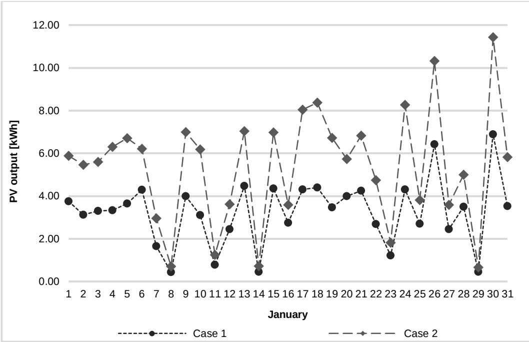


Figure A 18 PV output for January

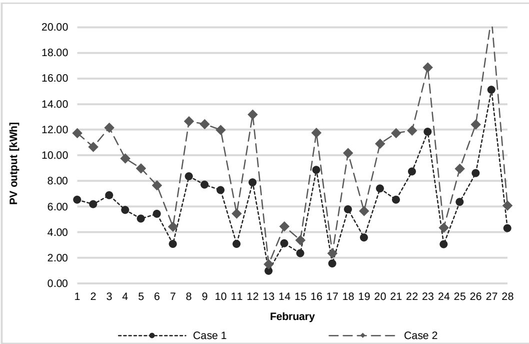


Figure A 19 PV output for February

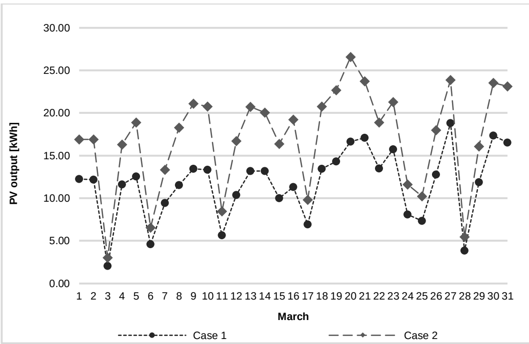


Figure A 20 PV output for March

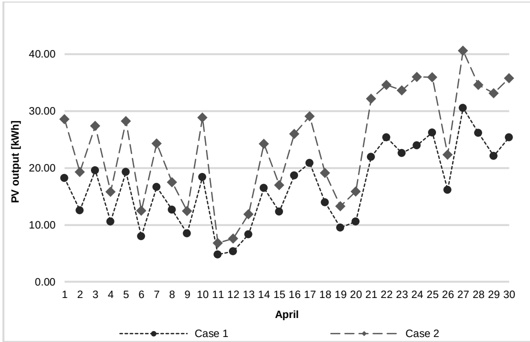


Figure A 21 PV output for April

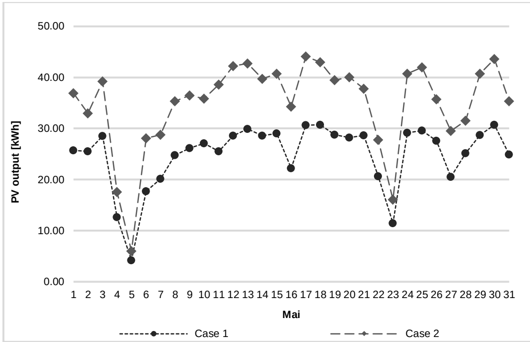


Figure A 22 PV output for Mai

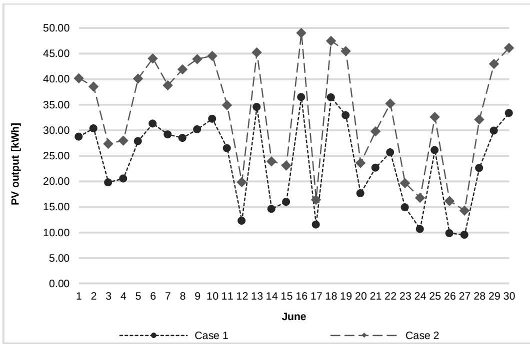


Figure A 23 PV output for June

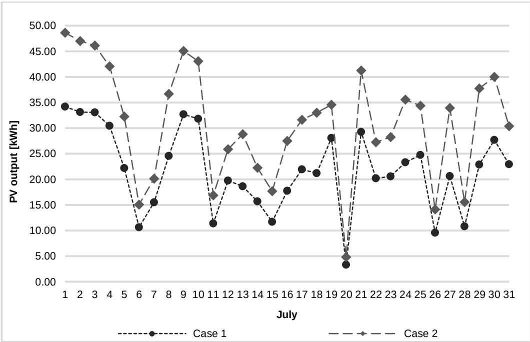


Figure A 24 PV output for July

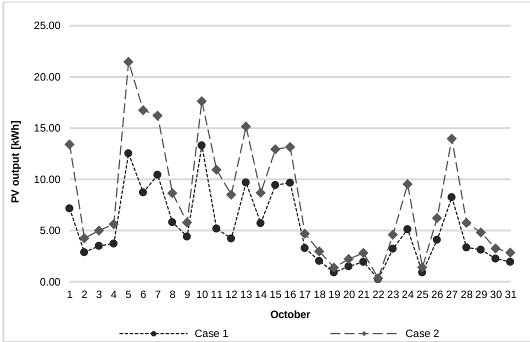


Figure A 27 PV output for October

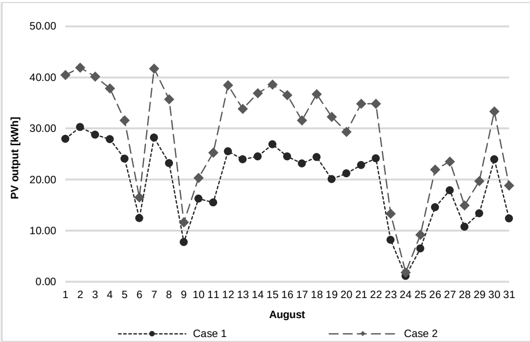


Figure A 25 PV output for August

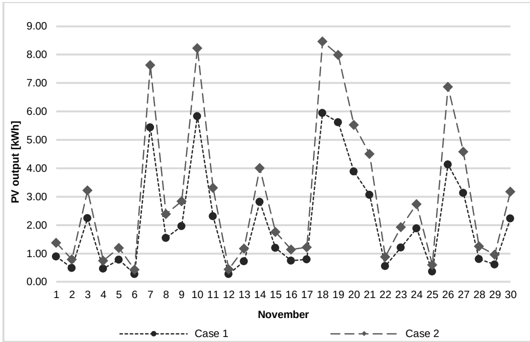


Figure A 28 PV output for November

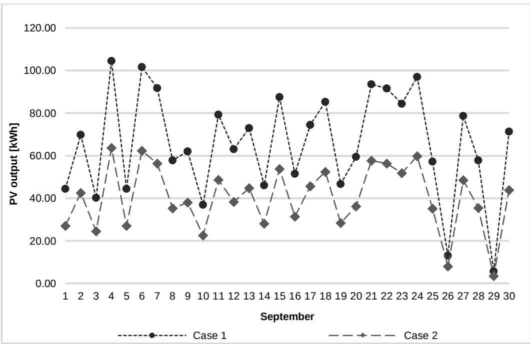


Figure A 26 PV output for September

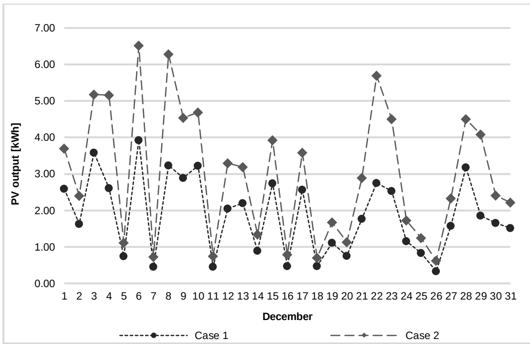


Figure A 29 PV output for December

7.8 Weather data

Table A 6 Weather data file for January (source EDSL TAS. 2012a)

January				
Day	Global Radiation (W)	Cloud Cover (0-1)	External Temp. (°C)	Wind Speed (m/s)
1	51.04	0.36	-5.90	3.53
2	49.67	0.37	-10.13	2.24
3	50.58	0.40	-11.19	1.17
4	58.67	0.23	-7.49	2.59
5	61.67	0.18	-4.56	3.16
6	52.75	0.40	-5.37	1.14
7	27.67	0.70	3.63	3.25
8	10.29	0.94	3.23	1.83
9	60.67	0.46	2.40	1.87
10	57.92	0.30	2.75	1.52
11	14.25	0.78	1.20	2.30
12	32.08	0.96	5.22	2.78
13	59.71	0.40	5.83	2.41
14	10.92	0.75	5.38	3.17
15	61.33	0.44	4.75	1.94
16	29.33	0.65	9.87	3.58
17	71.21	0.32	4.94	0.88
18	74.04	0.12	6.65	3.03
19	62.67	0.31	5.20	2.14
20	46.42	0.71	9.95	5.93
21	57.04	0.60	10.22	5.20
22	44.54	0.63	12.44	7.70
23	18.25	0.90	9.08	6.15
24	71.88	0.50	12.40	7.08
25	34.33	0.67	6.17	6.90
26	83.83	0.41	2.14	8.51
27	32.42	0.64	0.97	6.63
28	42.79	0.89	1.17	2.43
29	8.83	0.97	-1.11	1.90
30	92.42	0.40	-6.33	1.65
31	48.63	0.58	-10.45	1.05

Table A 7 Weather data file for February (source EDSL TAS. 2012a)

February				
Day	Global Radiation (W)	Cloud Cover (0-1)	External Temp. (°C)	Wind Speed (m/s)
1	98.04	0.32	-7.71	0.77
2	88.67	0.13	-6.18	0.41
3	102.63	0.10	-2.23	0.96
4	81.54	0.25	-5.34	0.86
5	74.75	0.27	-3.26	1.86
6	59.25	0.69	4.36	4.50
7	37.38	0.97	2.81	2.82
8	97.46	0.44	0.68	1.83
9	100.46	0.17	0.14	2.24
10	97.33	0.14	-0.05	1.32
11	46.63	0.51	-0.29	0.95
12	108.75	0.31	-0.37	2.48
13	16.63	0.71	-0.56	1.93
14	38.00	1.00	0.53	3.07
15	30.13	1.00	1.25	1.93
16	82.58	0.65	-0.70	2.16
17	23.38	0.85	-0.01	5.05
18	89.29	0.79	3.88	3.89
19	48.54	0.82	3.77	4.70
20	85.88	0.72	2.93	6.07
21	97.42	0.55	2.54	8.55
22	86.71	0.61	-3.01	5.58
23	128.25	0.43	-4.39	6.33
24	38.75	0.81	-3.91	8.96
25	67.00	1.00	-2.10	8.05
26	93.08	0.70	-1.42	3.93
27	147.58	0.29	-3.74	1.18
28	50.29	0.80	-1.48	1.21

Table A 8 Weather data file for March (source EDSL TAS. 2012a)

March				
Day	Global Radiation (W)	Cloud Cover (0-1)	External Temp. (°C)	Wind Speed (m/s)
1	120.42	0.70	1.41	3.13
2	119.71	0.52	1.41	2.18
3	28.71	0.85	-1.33	3.34
4	116.25	0.75	-3.30	4.94
5	138.71	0.47	-4.03	4.93
6	51.63	0.83	0.19	5.84
7	101.17	0.81	2.19	4.56
8	142.88	0.44	0.03	5.11
9	166.13	0.17	-1.23	1.97
10	159.46	0.12	0.73	1.59
11	68.38	0.67	4.53	4.11
12	130.50	0.60	0.78	1.11
13	163.04	0.26	4.58	1.42
14	154.21	0.23	5.36	1.15
15	133.04	0.38	5.25	0.80
16	153.08	0.35	10.14	2.67
17	74.38	0.82	10.75	6.54
18	166.79	0.49	14.78	5.56
19	178.17	0.30	12.03	5.49
20	207.21	0.12	10.57	2.21
21	171.67	0.13	11.53	1.03
22	144.29	0.37	14.77	1.33
23	143.88	0.51	12.58	4.82
24	87.13	0.84	8.71	1.71
25	77.67	0.97	5.61	3.42
26	132.38	0.69	3.03	4.25
27	158.21	0.45	2.00	4.67
28	48.04	0.85	0.21	7.54
29	112.75	0.90	1.50	6.24
30	165.17	0.60	2.43	3.56
31	163.83	0.53	4.44	1.62

Table A 9 Weather data file for April (source EDSL TAS. 2012a)

April				
Day	Global Radiation (W)	Cloud Cover (0-1)	External Temp. (°C)	Wind Speed (m/s)
1	209.54	0.33	6.41	3.10
2	151.21	0.62	6.46	2.95
3	198.04	0.34	6.61	1.27
4	125.25	0.62	8.49	1.05
5	211.42	0.36	8.68	6.60
6	97.79	0.74	7.41	2.53
7	184.67	0.60	8.68	5.48
8	123.21	0.74	7.78	5.27
9	94.46	0.80	6.25	3.89
10	234.46	0.42	5.50	1.83
11	57.75	0.86	3.54	2.30
12	62.08	1.00	5.34	1.69
13	88.04	0.91	7.60	1.57
14	179.71	0.57	10.42	1.24
15	120.04	0.87	10.50	1.95
16	184.29	0.60	10.34	4.50
17	214.04	0.41	10.52	2.72
18	133.67	0.76	11.48	7.12
19	98.58	0.92	13.26	5.90
20	119.67	0.79	10.28	1.25
21	244.17	0.34	12.30	3.08
22	250.17	0.18	14.78	1.66
23	255.75	0.10	16.39	1.27
24	273.79	0.11	17.59	3.95
25	257.38	0.15	18.82	4.64
26	165.04	0.63	17.05	4.13
27	283.96	0.20	17.63	2.84
28	242.88	0.19	17.41	1.88
29	247.17	0.22	17.80	2.01
30	257.96	0.19	16.20	2.27

Table A 10 Weather data file for Mai (source EDSL TAS. 2012a)

Mai				
Day	Global Radiation (W)	Cloud Cover (0-1)	External Temp. (°C)	Wind Speed (m/s)
1	272.33	0.18	16.61	1.99
2	226.46	0.29	17.04	1.40
3	284.21	0.18	18.40	3.76
4	127.25	0.83	13.83	3.98
5	53.21	1.00	10.59	2.83
6	227.00	0.66	12.80	1.74
7	217.29	0.57	15.86	1.74
8	264.42	0.33	16.67	1.49
9	267.96	0.30	17.06	2.00
10	253.92	0.33	17.34	2.38
11	297.42	0.14	17.53	2.54
12	316.17	0.09	18.09	2.68
13	313.92	0.11	18.40	2.62
14	286.04	0.14	18.40	1.99
15	296.75	0.19	18.68	4.12
16	265.58	0.38	17.59	4.46
17	325.46	0.13	17.42	2.08
18	309.83	0.08	19.03	3.13
19	284.17	0.18	20.68	2.67
20	299.96	0.23	21.22	2.92
21	270.00	0.32	19.88	4.00
22	191.83	0.62	13.64	5.47
23	117.83	0.92	13.73	1.86
24	286.17	0.35	16.22	1.68
25	307.54	0.16	19.40	1.15
26	241.63	0.28	20.65	0.78
27	222.17	0.52	21.38	1.19
28	197.00	0.52	17.55	4.25
29	279.71	0.27	17.80	3.63
30	314.21	0.14	19.75	2.05
31	256.83	0.41	18.33	4.87

Table A 11 Weather data file for June (source EDSL TAS. 2012a)

June				
Day	Global Radiation (W)	Cloud Cover (0-1)	External Temp. (°C)	Wind Speed (m/s)
1	288.67	0.29	19.12	2.61
2	267.13	0.37	21.26	2.62
3	196.92	0.70	17.04	6.19
4	198.38	0.66	18.76	2.67
5	292.13	0.25	21.13	2.15
6	322.00	0.11	23.15	1.53
7	272.46	0.30	23.46	2.98
8	313.00	0.14	20.58	2.53
9	327.96	0.09	21.17	3.44
10	321.00	0.10	23.93	4.91
11	236.63	0.31	23.43	1.68
12	156.04	0.70	14.60	6.35
13	301.25	0.36	16.57	3.67
14	188.13	0.60	16.29	4.57
15	172.92	0.85	16.06	3.38
16	340.17	0.25	16.66	3.11
17	120.63	0.79	15.38	3.62
18	319.58	0.41	18.24	3.82
19	319.38	0.10	21.99	1.88
20	169.58	0.63	20.32	1.69
21	201.42	0.65	18.99	2.46
22	241.00	0.46	19.13	2.10
23	136.54	0.77	19.81	1.94
24	129.67	0.81	16.88	3.80
25	207.13	0.64	15.39	3.53
26	133.88	0.79	13.13	3.21
27	112.33	0.89	14.51	3.19
28	230.67	0.67	14.25	3.90
29	312.71	0.30	16.35	2.45
30	329.42	0.16	18.50	1.80

Table A 12 Weather data file for July (source EDSL TAS. 2012a)

July				
Day	Global Radiation (W)	Cloud Cover (0-1)	External Temp. (°C)	Wind Speed (m/s)
1	346.79	0.08	16.93	2.37
2	341.21	0.04	20.07	1.82
3	329.79	0.05	23.93	3.11
4	304.58	0.18	26.00	3.63
5	248.67	0.42	24.53	1.92
6	112.21	0.83	16.88	4.94
7	133.88	0.86	16.00	4.60
8	281.92	0.50	17.23	2.40
9	321.04	0.14	20.21	2.25
10	308.42	0.20	23.13	3.75
11	133.79	0.70	15.28	4.98
12	182.00	0.75	13.37	4.18
13	226.92	0.65	13.56	5.38
14	163.08	0.78	15.52	3.85
15	139.21	0.82	16.85	3.67
16	223.25	0.64	20.24	3.80
17	230.17	0.50	21.67	2.76
18	257.33	0.44	22.61	2.02
19	220.42	0.47	21.81	2.15
20	44.92	0.89	15.66	2.80
21	301.25	0.42	17.95	4.18
22	198.71	0.62	16.81	4.51
23	198.50	0.58	16.85	4.32
24	272.71	0.39	20.42	4.83
25	253.04	0.28	19.90	2.20
26	104.79	0.78	17.09	3.05
27	280.83	0.50	18.60	2.72
28	114.75	0.87	17.68	3.96
29	298.38	0.32	20.62	3.53
30	297.71	0.10	23.57	2.83
31	208.79	0.43	21.81	4.11

Table A 13 Weather data file for August (source EDSL TAS. 2012a)

August				
Day	Global Radiation (W)	Cloud Cover (0-1)	External Temp. (°C)	Wind Speed (m/s)
1	292.50	0.20	19.48	2.38
2	303.38	0.11	20.94	2.38
3	290.88	0.09	23.71	1.70
4	270.58	0.17	25.53	1.77
5	217.25	0.30	25.23	2.11
6	111.13	0.71	20.08	3.36
7	311.92	0.19	19.40	2.35
8	283.58	0.21	20.29	1.60
9	88.29	0.79	18.83	2.07
10	128.08	0.77	18.78	5.00
11	194.25	0.56	17.49	3.68
12	288.83	0.16	20.34	1.92
13	237.04	0.22	22.58	1.60
14	277.88	0.13	24.29	2.93
15	283.46	0.09	25.33	3.28
16	275.50	0.09	25.06	2.05
17	228.88	0.23	24.05	2.99
18	276.38	0.16	20.43	2.53
19	259.42	0.18	19.26	1.56
20	211.21	0.36	20.37	1.42
21	264.33	0.15	24.55	3.61
22	254.67	0.05	25.26	2.30
23	106.58	0.64	21.82	3.22
24	21.00	0.95	14.44	2.13
25	72.79	1.00	13.41	1.65
26	168.13	0.71	15.02	1.96
27	169.04	0.61	14.77	3.25
28	112.00	0.77	13.65	3.91
29	151.79	0.73	12.51	3.73
30	243.08	0.30	15.38	2.90
31	153.75	0.55	12.37	4.10

Table A 14 Weather data file for September (source EDSL TAS. 2012a)

September				
Day	Global Radiation (W)	Cloud Cover (0-1)	External Temp. (°C)	Wind Speed (m/s)
1	109.25	0.75	12.71	4.57
2	134.83	0.75	14.49	4.05
3	92.38	0.92	14.67	3.66
4	188.08	0.60	14.68	4.53
5	108.38	0.73	10.47	4.16
6	198.46	0.47	12.18	3.13
7	223.21	0.16	12.14	1.25
8	145.42	0.61	15.88	1.59
9	177.46	0.36	20.00	1.80
10	104.92	0.63	17.86	3.18
11	175.58	0.58	17.15	3.00
12	121.33	0.55	15.02	2.34
13	192.92	0.23	17.27	2.57
14	100.71	0.69	15.36	2.12
15	199.79	0.35	16.82	3.26
16	121.50	0.53	16.61	2.90
17	159.50	0.50	16.45	3.00
18	194.50	0.31	14.96	2.23
19	111.67	0.75	13.09	2.45
20	121.88	0.80	14.52	3.41
21	187.71	0.26	16.89	3.98
22	184.92	0.13	17.72	4.17
23	178.67	0.13	18.29	2.16
24	188.54	0.11	20.48	3.44
25	142.58	0.32	18.34	3.42
26	29.42	0.85	12.58	4.80
27	175.50	0.36	13.10	3.16
28	138.79	0.43	12.09	1.79
29	14.58	0.88	10.41	2.02
30	171.04	0.32	8.01	2.53

Table A 15 Weather data file for October (source EDSL TAS. 2012a)

October				
Day	Global Radiation (W)	Cloud Cover (0-1)	External Temp. (°C)	Wind Speed (m/s)
1	112.58	0.50	13.48	5.46
2	38.71	0.90	14.49	5.59
3	41.79	1.00	13.07	2.21
4	46.83	0.95	11.81	2.35
5	165.29	0.26	12.77	2.04
6	149.58	0.19	15.00	1.85
7	125.21	0.30	15.28	2.04
8	68.71	0.74	16.24	2.08
9	43.75	0.91	13.00	3.62
10	128.38	0.54	10.44	1.39
11	100.83	0.50	11.77	1.13
12	80.63	0.64	14.10	2.12
13	119.29	0.36	15.82	2.25
14	72.79	0.63	17.42	5.05
15	103.42	0.60	14.57	1.49
16	91.83	0.59	13.07	2.42
17	40.42	0.88	9.66	2.35
18	28.33	1.00	6.58	2.78
19	15.79	1.00	6.22	3.02
20	22.13	1.00	7.16	1.13
21	26.58	1.00	7.27	1.45
22	7.25	1.00	7.71	1.90
23	39.71	1.00	11.37	2.82
24	81.54	0.65	10.87	1.58
25	16.25	0.86	7.52	2.01
26	51.33	0.95	5.04	2.12
27	110.96	0.32	3.83	1.16
28	47.58	0.55	3.00	1.42
29	41.63	0.81	3.23	1.33
30	30.54	0.96	2.82	1.70
31	27.21	1.00	3.45	3.79

Table A 16 Weather data file for November (source EDSL TAS. 2012a)

November				
Day	Global Radiation (W)	Cloud Cover (0-1)	External Temp. (°C)	Wind Speed (m/s)
1	15.88	1.00	4.93	4.12
2	10.92	1.00	5.05	3.33
3	29.33	1.00	6.43	2.84
4	10.33	1.00	6.74	1.59
5	14.04	1.00	9.29	2.98
6	7.83	1.00	10.10	2.72
7	56.92	0.75	10.48	1.06
8	24.63	0.90	9.39	1.22
9	26.04	0.98	9.21	2.54
10	61.54	0.69	6.45	1.94
11	29.88	0.87	5.38	3.38
12	7.88	1.00	0.08	2.73
13	14.46	1.00	0.73	2.01
14	34.33	1.00	1.15	2.88
15	18.08	1.00	1.67	1.99
16	13.21	1.00	2.46	4.70
17	13.88	1.00	-0.08	3.86
18	63.79	0.47	-3.35	2.05
19	60.29	0.19	-5.21	1.18
20	43.88	0.55	-4.23	1.81
21	37.21	0.84	-2.72	3.21
22	11.42	0.97	-1.49	3.41
23	21.54	1.00	-3.99	2.85
24	25.46	1.00	-1.33	4.52
25	9.13	1.00	-1.05	3.37
26	60.38	0.58	-3.93	3.80
27	39.08	0.71	-4.70	4.90
28	14.17	0.95	-5.22	1.58
29	12.21	1.00	-3.93	0.92
30	28.71	1.00	-1.85	1.06

Table A 17 Weather data file for December (source EDSL TAS. 2012a)

December				
Day	Global Radiation (W)	Cloud Cover (0-1)	External Temp. (°C)	Wind Speed (m/s)
1	32.83	0.99	-1.79	4.93
2	23.04	1.00	-1.63	1.88
3	43.21	0.75	6.16	3.07
4	47.38	0.57	3.25	1.33
5	12.83	0.87	1.80	1.74
6	60.33	0.47	3.20	2.37
7	9.63	0.75	-1.97	2.62
8	58.67	0.49	2.57	3.57
9	43.13	0.41	7.73	4.55
10	43.29	0.50	8.91	4.48
11	10.17	0.82	5.75	4.57
12	30.63	0.82	3.39	5.84
13	28.04	0.86	3.65	1.44
14	14.46	0.97	3.95	1.48
15	35.42	0.84	4.39	1.60
16	10.96	0.92	3.78	2.58
17	33.38	0.78	5.14	6.56
18	9.50	0.88	4.58	2.13
19	17.38	1.00	1.50	1.17
20	12.71	1.00	7.92	3.15
21	27.58	0.89	7.91	3.82
22	54.67	0.38	4.00	5.46
23	42.29	0.37	5.15	3.51
24	17.79	0.84	3.50	3.68
25	13.67	1.00	1.75	4.38
26	9.42	1.00	-0.30	2.00
27	22.13	1.00	-0.11	5.64
28	37.46	1.00	0.99	3.84
29	38.25	0.80	-0.38	0.61
30	22.67	0.89	-2.96	0.85
31	21.38	1.00	-0.02	1.51